# A FRAMEWORK FOR COORDINATED MODELS OF ARCHITECTURAL PRECAST CONCRETE FAÇADES

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# A FRAMEWORK FOR COORDINATED MODELS OF ARCHITECTURAL PRECAST CONCRETE FAÇADES

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For my girls; Jennifer, Lida, and Edie

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During the Spring 2018 semester, I was able to shadow a design studio in the Master of Architecture program in the School of Architecture at Georgia Tech. The studio, taught by Professor Tristan Al-Haddad, was fittingly focused on developing proposals for precast concrete buildings. I am grateful to Professor Al-Haddad and all of the students in the studio not only for including me in their discussions – which were helpful to developing my own thoughts and research proposal – but also for allowing me to include and test their work herein.

This investigation began as a collaborative project between Georgia Tech's Digital Building Lab and Castone Corporation, an architectural precast concrete fabricator, exploring the possibilities of incorporating digital modelling into their existing workflow. Knowledge shared with me by Mo Wright, Stephen Farr, Chris Cox, and Robert Adkins was instrumental in forming initial research proposals. After further development, I had the opportunity to present progress to various personnel with Gate Precast Company. Conversations with Mo Wright, Nathan Brooks, Tony DiBella, Robert Fisher, and Sam Taylor were particularly informative. The willingness of each of these industry experts to share their knowledge and provide feedback was invaluable and I am very appreciative. It is my hope that this work continues and enhances similar future interaction between designers and fabricators, of precast and of all kinds.

Thank you to my parents for their encouragement in architecture and all things. And finally, my love and thanks to my amazing wife Jennifer and our strong, curious, and inspiring daughters, Lida and Edie, for their patience, encouragement, and support during this undertaking and for being my foundation always.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| *AEC* | Architecture Engineering Construction |
| *AI* | Artificial Intelligence |
| *APC* | Architectural Precast Concrete |
| *BIM* | Building Information Modelling |
| *BPMN* | Business Process Model and Notation |
| *DBB* | Design Bid Build |
| *DBL* | Digital Building Laboratory |
| *DSSBF* | Drawing Shape Structure Behavior Function |
| *ER* | Entity-relationship Model |
| *GFRC* | Glass Fiber Reinforced Concrete |
| *Num* | Number of |
| *PCI* | Precast/Prestressed Concrete Institute |
| *SBF* | Structure Behavior Function |
| *SysML* | Systems Modelling Language |
| *UoD* | Universe of Discourse |
| *UML* | Unified Modelling Language |

# LIST OF KEY TERMS

| | |
|---|---|
| *Bounding box* | The three-dimensional limits of an individual piece of precast and all connection and tolerance requirements surrounding it |
| *Design intent* | Set of documents or models representing design intentions |
| *Design intention* | Aesthetic, formal and spatial organization goals for a project |
| *Frame* | Structured knowledge system for organizing relationships, also known as knowledge frame |
| *Framework* | An architectural pattern that provides an extensible template for applications within a domain. From [Booch et al, 1999] |
| *Global* | Representation of an overall building, also called “top-down” |
| *Local* | Representation of individual architectural components, also called “bottom-up” |
| *Map* | How instances of global and local models correlate to one another |
| *Meta model* | A method for organizing relationships and defining the explicit construction and rules for building models within a specific domain. From [Pidcock, 2003] |
| *Model* | In this work, model refers to a building representation developed within computer software |
| *Panel* | An individual piece of precast |
| *Panel boundary* | May define an individual piece of precast or the parameters of an important architectural element such as a reveal |
| *Panel model* | Parametric model of an individual piece of precast and all of its geometric features |
| *Panelization* | The pattern that defines the bounds of individual pieces of precast (may differ from panel boundary or surface pattern) |
| *Parametric model* | A digital model building representation created using computer software that allows flexibility of defined geometry through variables |
| *Precast* | In this work, precast refers to architectural precast concrete |

*Process model* A set of graphics used to describe and organize relationships, flows of information, and activities, created in order to communicate or improve upon such relationships and procedures

*Region* Defined portion of a surface within which a surface pattern is described or to which a panel is applied

*Scaffold model* Parametric model describing the relationships between key building systems and to which additional components can be associated

*Surface pattern* A set of panel boundaries defined across the extent of a surface or region

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* For precedent building image references, see Appendix A.

# SUMMARY

Architects are often unaware of details, constraints, and variables that define and deliver architectural components. Many factors such as constructability, budget, or scheduling commitments, force changes to design concepts – potentially resulting in time-consuming redesign or loss of design aspirations – because incorporation of fabrication and expert knowledge occurs too late in the process. At the same time, fabricators, obligated to re-model these components – typically via error-prone manual translation – may be unaware of critical architectural properties envisioned but difficult to represent in design intent documents.

The focus of this dissertation is to establish a new framework for coordination among project actors, linking currently disparate global and local descriptions of architectural intent and corresponding components via parametric digital models, with the aim of improving representations, enabling more informed conversations, and streamlining exchanges during early stages of design. In order to show the potential of this framework, research is focused on architectural precast concrete façades. Building façades are especially relevant to both architectural theory and practice as they are critical to a buildings' character but remarkably complex in assembly. The architectural precast façade offers, in particular, a system whose parts are discreet through surface panelization, customizable via extensive features, and fundamental to the overall buildings' aesthetic.

Protocols and techniques for generating and linking customizable digital models for coordination are documented for a variety of surface patterns and panel feature types found in precedent buildings with architectural precast concrete façades. These models are used

to demonstrate the process of developing parametric maps, both as a means of engaging issues of fabrication in early stages of design as well as to demonstrate benefits of incorporating such maps in future state workflows. Knowledge gained from recording various processes undertaken, conversations held, and documents produced by precast fabricators during the shop drawing phase of their work informs the parametric maps from both global and local perspectives. The strategies from the precedent analysis are then implemented through the exploration of design and fabrication issues raised by novel student proposals.

The research suggests that the current disconnect between architectural intent and fabrication knowledge contributes to limited design exploration, and ultimately, reduces use of architectural precast concrete façades and furthermore, that linked digital models can stimulate interaction between designers and fabricators – bridging currently disparate workflows and value systems – while simultaneously enabling design exploration, incorporating fabrication details, and allowing new opportunities for precast buildings to emerge.

# CHAPTER 1. INTRODUCTION

Framework: An architectural pattern that provides an extensible template for applications within a domain. [Booch et al, 1999]

This research focuses on establishing a new framework for coordination among project actors, linking currently disparate "global" and "local" models of architectural precast concrete façades and panels via parametric digital models, with the aim of improving representations, enabling more informed conversations, and streamlining exchanges during early design. Documentation and digital models of existing precedent buildings will demonstrate the process of developing various parametric "maps," both as a means of engaging issues of fabrication in early design as well as to demonstrate benefits of incorporating such processes in future state workflows. Knowledge gained from recording various processes undertaken, conversations with, and documents produced by precast fabricators during the shop drawing phase of their work informs these models from both global and local perspectives.

## 1.1 Problem

In the current state of the conventional Design-Bid-Build process, designer and fabricator modes of working and depicting projects are disconnected. This is partly due to standard contractual procedures; the designer is not required to provide means and methods, but a general direction for "design intent." Frequently, therefore, designers are unaware of details, constraints, and variables that define architectural components at the "local" level. Moreover, even if the designer develops digital models of architectural components as they envision them being built, this does not guarantee that the parts will be built as modeled. Instead, upon receipt of design intent documents, each fabricator subsequently adds their own industry knowledge, remodeling components often via error-prone manual translation. Through this process, many factors – for example, constructability, budget, or scheduling commitments – may force changes to the original design intent, resulting in time-consuming remodeling or even loss of significant design features due to value engineering. This research is focused on linking digital models of these global and local building descriptions, both as a means of uncovering currently unknown fabrication and assembly details as well as to demonstrate benefits of incorporating such processes in future state work flows. While these issues are not isolated to a specific aspect of built work, in order to show the potential of the concept, research is focused on a particular system; architectural precast concrete façades. Architectural precast concrete is distinguished from other forms of precast concrete in that such pieces are critical components of a building façade – they have a high-quality finish and are integral to the overall aesthetic of the building design. Furthermore, related to the aforementioned disconnect in current typical projects, according to the PCI Design Handbook, "the successful and economical use of architectural precast concrete requires not only a clear understanding of the production and erection methods, but also good knowledge of the structural limitations of the product." [Precast/Prestressed Concrete Institute, 1999] This work suggests that – because such industry knowledge is not incorporated until late in the process – design ambitions are too often eschewed due to the looming risk that changes will be required, resulting in time-consuming remodeling or loss of significant architectural elements. On the other hand, linked digital models can stimulate interaction between designers and fabricators – bridging currently disparate workflows and value systems – while simultaneously enabling design exploration and incorporating fabrication details, and allowing new opportunities for precast buildings to emerge.

There are three main benefits that this research endeavors to address: increased design agency, reduced remodeling, and enabling additional routines. Despite current contractual limitations, if designers and fabricators were able to coordinate architectural components earlier in the process, as opposed to during the later shop drawing phase, projects teams could avoid value engineering and curb redesign time or being stuck with undesirable building features. Furthermore, if models are coordinated early, design models could propagate directly to for-construction models. Such models could also serve as more accurate representations for additional routines such as daylight and shadow studies, energy and building performance simulation, and automated detailing.

## 1.2 Architectural precast concrete

Since its development in the early 1900s [Slaton, 2001], designers and inventors alike have been fascinated with experimenting with precast concrete. As a material and a means of production, the plasticity and efficiency of precast concrete obviously captures the imagination of those looking to push the boundaries of both construction procedures and architectural expression. Seemingly endless proliferations of precast systems were explored through much of the early twentieth century (The Ransome Unit System focused on creating a catalogue of precast parts [e-flux, 2018], François Hennebique’s work integrated elements such as column and beam together [Macbeth, 1998], Thomas Edison developed a patent for a uni-pour house [Arch Daily, 2018], to name a few.) Meloy (2016) provides a fascinating historical account of the technological evolution and significance of architectural precast wall panels. While each varying system is fascinating in their own right, this research focuses on panelized façade systems; buildings with architectural precast concrete façade panels that are integral to the overall aesthetic expression of the building. Development of the first precast panelled buildings is credited to John Alexander Brodie (1858-1934), an English Civil Engineer, who proposed a revolutionary approach for the construction of low-cost homes – use of offsite construction and transport of large pieces to the site for quick assembly. [Chambre Hardman Archive, 2018; Concrete Producer, 2017] Brodie's work influenced Grosvenor Atterbury (1869-1956), an architect from New York City, who further enhanced methods of form making and assembly. [Pennoyer and Walker, 2009] Figure 1 shows a construction photo of one of Atterbury's experimental houses built in Sewaren, New Jersey in 1910. [Standardized Housing Corporation, 1917]

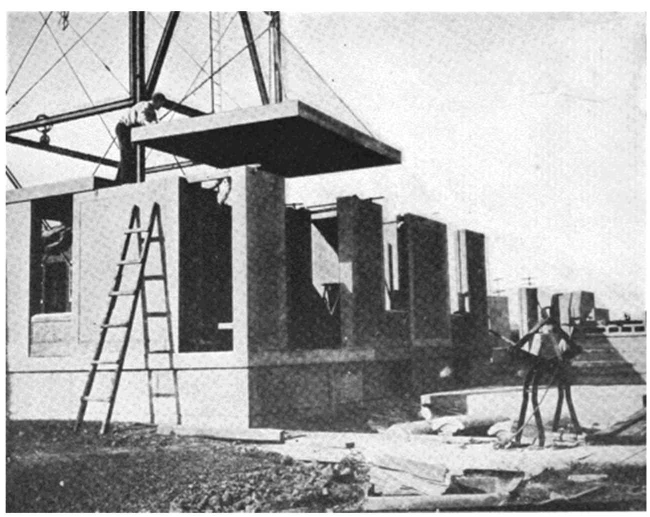


**Figure 1: Construction photo, Atterbury's experimental prefabricated house in Sewaren, New Jersey. From [Standardized Housing Corporation, 1917]**

The Precast/Prestressed Concrete Institute lauds architectural precast concrete for its ability to be "produced in a wide variety of shapes and finishes... from simple to complex… color, pattern and texture," noting in particular that "the combination of finish and shape contribute[s] to the architectural expression and finished appearance of the structure." [Precast/Prestressed Concrete Institute, 1999] While this research aims to include a wide variety of precast possibilities, architectural precast concrete façade panels included in this work assume:

- Pieces are custom-designed and unique to a particular building
- Pieces are cast by pouring wet concrete into forms
- Pieces are cast at a location other than the final position on the building and, after curing, are then transported to the site for installation
- Pieces are designed as an integral part of the building exterior wall

The above constraints exclude some concrete work (cast-in-place concrete, cement board products, and pieces used in applications other than walls, to name a few). However, this scope intentionally does not limit precast in terms of material make-up (including traditional mixes or varieties such as GFRC (Glass Fiber Reinforced Concrete)) or production method (such as Mo-Sai [Freedman, 2004] or Schokbeton [Schokbeton, 2018]). Instead, the focus of this work is placed on process and modelling. In the course of designing and fabricating architectural precast concrete façades, designers and fabricators develop distinct descriptions (such as digital models) which may or may not align to one another. Design intent for the overall building façades must be discretised into individual pieces and translated – using expert knowledge regarding panel features, form construction, transportation and assembly limitations, and more – into directives for fabrication. This research seeks to clarify such translations, developing protocols and techniques for generating and linking customizing models for coordination. While it is true that particular concrete mix designs or construction approaches may permit vastly different outcomes, this work focuses on improving representations, enabling more informed conversations, and streamlining exchanges of architectural precast concrete façades during early stages of design in order to allow exploration of design and fabrication possibilities regardless of means and methods.

One of the masters of these custom, expressive kinds of panelized precast concrete façades was Marcel Breuer (1902-1981). In his memoir of his former employer, [Gatje, 2000] writes "Breuer didn't invent precast concrete but he became one of its most sophisticated users." Breuer himself stated that "the use of precast concrete is the most important change in the art of building since World War II. You can sculpt concrete; you can mold it; you can chisel it. It increases the vocabulary of architectural expression." Pyburn (2008) further elaborates on the role of precast technology in post war architectural design. It is this kind of work that this research aspires to capture; projects that transcend assumptions about precast, question its weight, perforation, transparency, depth, and more. This work, therefore, omits parking garages, bridges and other infrastructure, panels with brick or other facing, and other special elements such as arches, columns, cornices, etc. in order to instead focus on panelized façade systems; buildings with architectural precast concrete façades wherein precast is integral to the aesthetic expression of the building.

A list of buildings that are pertinent to this research is shown in Table 1. Additional information on each these buildings – including references for images – can be found in Appendix A.

**Table 1: Architectural precast concrete precedent buildings**

| Building name | Location | Architect | Date completed |
|---|---|---|---|
| Ennis (Ennis-Brown) Residence | Los Angeles, CA | Frank Lloyd Wright | 1924 |
| Freeman Residence | Hollywood, CA | Frank Lloyd Wright | 1924 |
| Millard Residence (La Miniatura) | Pasadena, CA | Frank Lloyd Wright | 1924 |
| Storer Residence | Hollywood, CA | Frank Lloyd Wright | 1924 |
| Philadelphia Police Department Headquarters (Roundhouse) | Philadelphia, PA | Geddes, Brecher, Qualls and Cunningham | 1959 |
| Denver Hilton Hotel (now Sheraton Denver Downtown Hotel) | Denver, CO | I.M.Pei & Associates | 1960 |
| U.S. Embassy London | London, England | Eero Saarinen | 1960 |
| IBM Research Center | La Gaude, France | Marcel Breuer and Robert F. Gatje | 1962 |
| Pan Am Building | New York, NY | Emery Roth & Sons, Pietro Belluchi and Walter Gropius | 1963 |
| Torin Corporation | Nivelles, Belgium | Marcel Breuer and Hamilton P. Smith and Andre and Jean Polak | 1964 |
| U.S. Embassy Dublin | Dublin, Ireland | John M Johansen | 1964 |
| Bank Lambert | Brussels, Belgium | Gordon Bunshaft (SOM) | 1965 |
| Torin Corporation Administration Building | Torrington, Connecticut | Marcel Breuer and Herbert Beckhard | 1966 |
| Sarget-Ambrine Headquarters and Pharmaceutical Laboritories | Merignac, France | Marcel Breuer and Robert F. Gatje | 1967 |

| | | | |
|---|---|---|---|
| Department of Housing and Urban Development Headquarters | Washington, DC | Marcel Breuer, Nolen-Swinburne and Associates, and Herbert Beckhard | 1968 |
| Flaine Hotel | Chamonix, France | Marcel Breuer and Robert F. Gatje | 1968 |
| Armstrong Rubber Company Headquarters | West Haven, CT | Marcel Breuer and Robert F. Gatje | 1970 |
| CBR building | Brussels, Belgium | Constantin Brodzki and Marcel Lambrichs | 1970 |
| University of Massachusetts Murray Lincoln Campus Center | Amherst, MA | Marcel Breuer and Herbert Beckhard | 1970 |
| Yale University Becton Engineering and Applied Science Center | New Haven, CT | Marcel Breuer and Hamilton P. Smith | 1970 |
| Colony Square | Atlanta, GA | Jova Daniels Busby | 1972 |
| IBM Administrative, Laboratory, and Manufacturing Facility | Boca Raton, Florida | Marcel Breuer and Robert F. Gatje | 1972 |
| Bankkantoor ASLK/BNP Parisbas | Brussels, Belgium | Marcel Lambrichs | 1974 |
| Department of Health, Education and Welfare Headquarters (Hubert H. Humphrey Federal Building) | Washington, DC | Marcel Breuer, Nolen-Swinburne and Associates, and Herbert Beckhard | 1976 |
| SUNY Buffalo Faculty of Engineering and Applied Science Building Complex | Amherst, MA | Marcel Breuer and Robert F. Gatje | 1978 |
| Atlanta Central Public Library | Atlanta, GA | Marcel Breuer and Hamilton P. Smith and Stevens and Wilkinson | 1980 |
| Adtran Corporate Headquarters | Huntsville, AL | Cooper Carry | 2000 |
| Duke University Nasher Museum of Art | Durham, NC | Rafael Viñoly Architects | 2005 |
| Airea | Mexico City, Mexico | VIDARQ | 2007 |
| Internal Revenue Service Center | Kansas City, MI | HOK and BNIM | 2007 |

| | | | |
|---|---|---|---|
| California State University San Bernardino College of Education | San Bernardino, CA | LPA | 2008 |
| American Pharmacists Association Headquarters | Washington, DC | Hartman-Cox Architects | 2009 |
| Indiana University Stadium North End Zone Addition | Bloomington, IN | RATIO Architects | 2009 |
| JE Dunn Corporate Headquarters | Kansas City, MO | HOK and BNIM | 2009 |
| Osage Prairie YMCA Natatorium Addition | Nevada, MO | SFS Architecture | 2009 |
| Paragon Santa Fe | Santa Fe, Mexico | IDEA Asociados Arquitectos | 2009 |
| Waldorf Astoria Chicago | Chicago, IL | Lucien Lagrange Studio | 2009 |
| City of Miami College of Policing, Miami-Dade School of Law Studies, Homeland Security, and Forensic Sciences | Miami, FL | AECOM | 2010 |
| Dubaski Career High School | Grand Prairie, TX | Corgan | 2010 |
| Place de L'Escarpement | Quebec, Canada | Pierre Martin Architecte | 2010 |
| Residence Le Saint-Jude | Alma, Canada | Eric Painchaud Architecte | 2010 |
| Teen Living Programs (Belfort House) | Chicago, IL | Hartshorne Plunkard Architecture | 2010 |
| The Century | Los Angeles, CA | Robert A.M. Stern | 2010 |
| U.S. Federal Courthouse | Jackson, MS | H3 Hardy Collaboration Architecture | 2010 |
| 900 North Glebe Road | Arlington, VI | Cooper Carry | 2011 |
| CEDETEC | Atizapan De Zaragoza, Mexico | LANDA Arquitectos | 2011 |
| Kauffman Center for the Performing Arts | Kansas City, MO | Safdie Architects and BNIM | 2011 |
| The National World War II Museum | New Orleans, LA | Voorsanger Architects | 2011 |
| 150 Rouse Boulevard | Philadelphia, PA | Digsau | 2012 |

| | | | |
|---|---|---|---|
| First United Methodist Church | Orlando, FL | CDH Partners | 2012 |
| James F. Battin United States Courthouse | Billings, MT | NBBJ | 2012 |
| Lincoln Park 2550 | Chicago, IL | Lucien Lagrange Studio | 2012 |
| Perot Museum of Nature and Science | Dallas, TX | Morphosis | 2012 |
| Pierresvives | Montpellier, France | Zaha Hadid Architects | 2012 |
| Tour Towers | Berlin, Germany | Barkow Leibinger | 2012 |
| Brown Deer School Field House | Brown Deer, WI | Plunkett Raysich Architects | 2013 |
| Clark and Grand Hotels | Chicago, IL | HOK | 2013 |
| Cobank Center | Greenwood Village, CO | Davis Partnership Architects | 2013 |
| Dollar General Distribution Center | Bessemer, AL | Leo A Daly | 2013 |
| ETS Student Housing | Monteal, Canada | Régis Côté et Associés | 2013 |
| Eurocenter | Mexico City, Mexico | TEN Arquitectos | 2013 |
| Hansberry College Prep | Chicago, IL | Wheeler Kearns Architects | 2013 |
| MuCEM | Marseille, France | Rudy Ricciotti | 2013 |
| Nanyang Technological University Learning Hub - The Hive | Singapore, Malaysia | Heatherwikc Studio and CPG Consultants | 2013 |
| Simons Galeries d'Anjou | Montreal, Canada | Lemaymichaud | 2013 |
| Textilmacher | Munich, Germany | tillicharchitektur | 2013 |
| The Ohio State University Chiller Plant | Columbus, OH | Ross Barney Architects | 2013 |
| Wisconsin Athletic Center | Menomonee Falls, WI | Eppstein Uhen Architects | 2013 |
| Burntwood School | London, England | Allford Hall Monaghan Morris | 2014 |
| City of Loveland Service Center | Loveland, CO | RNL Design | 2014 |
| Douglas L. McCrary Training Center | Pensacola, FL | Townes + architects | 2014 |
| L.A.  Marriott | Los Angeles, CA | GBD Architects | 2014 |

| | | | |
|---|---|---|---|
| Maritime and Seafood Industry Museum | Biloxi, MS | H3 Hardy Collaboration Architecture | 2014 |
| UCSF Mission Hall: Global Health & Clinical Sciences Building | San Francisco, CA | WRNS Studio | 2014 |
| University of Houston Health and Biomedical Sciences Building | Houston, TX | Shepley Bulfinch | 2014 |
| 250 High | Columbus, OH | NBBJ | 2015 |
| 84.51° Centre | Cincinnati, OH | Gensler | 2015 |
| Dumbo Townhouses | Brooklyn, NY | Alloy | 2015 |
| Florida International University Science Classroom | Miami, FL | Perkins + Will | 2015 |
| Gordon Food Service Home Office | Wyoming, MI | Integrated Architecture | 2015 |
| Hotel Residencial Nakâra | Cap d'Agde, France | Jacques Ferrier Architecture | 2015 |
| Italy Pavilion for the Milan Expo | Milan, Italy | Nemesi & Partners | 2015 |
| Suffolk University 20 Somerset Street | Boston, MA | NBBJ | 2015 |
| The Broad Museum | Los Angeles, CA | Diller Scofidio + Renfro | 2015 |
| UCSF Medical Center at Mission Bay | San Francisco, CA | Stantec | 2015 |
| 1200 Intrepid | Philadelphia, PA | BIG (Bjarke Ingels Group) | 2016 |
| 4260 Cortex | St. Louis, MO | Cannon Design | 2016 |
| Dior Miami Façade | Miami, FL | Barbaritobancel Architects | 2016 |
| Hempstead High School | Dubuque, IA | FEH Associates | 2016 |
| Judicial Council of California, Superior Court of California, County of Santa Clara, Family Justice Center Courthouse | San Jose CA | ZGF Architects | 2016 |
| King Abdullah Academy | Herndon, VA | Bowie Gridley Architects | 2016 |
| Roseville City Hall Annex | Roseville, CA | LPAS | 2016 |

| | | | |
|---|---|---|---|
| Terrace 459 at Parkside of Old Town | Chicago, IL | Landon Bone Baker Architects | 2016 |
| University of Chicago Campus North Residential Commons | Chicago, IL | Studio Gang | 2016 |
| University of Kansas Capitol Federal Hall | Lawrence, KS | Gensler and GastingerWalker& | 2016 |
| Colorado Center | Denver, CO | Tryba Architects | 2017 |
| Milwaukee Tool Headquarters | Brookfield, WI | Stephen Perry Smith Architects | 2017 |
| Minnesota Senate Building | St. Paul, MN | BWBR | 2017 |
| Universal Alloy Light Press Plant | Ball Ground, GA | Querkraft | 2017 |
| University of Florida Health Shands Cancer Hospital | Gainesville, FL | Flad Architects | 2017 |
| Frost Museum of Science | Miami, FL | Grimshaw and Rodriguez and Quiroga | 2018 |

Among the hundreds of buildings with architectural precast concrete façades that have been constructed and considered, only those included on the list in Table 1 will be referenced herein. This list of buildings was assembled from the following sources:

- Recommendations and presentation by Jack Pyburn [DOCOMOMO, 2015]
- Precast building examples collected by students in Professor Tristan Al-Haddad design studio in the Master of Architecture program in the School of Architecture at Georgia Tech, Spring 2018
- Catalogue of buildings on the Precast/Prestressed Concrete Institute's website [Precast/Prestressed Concrete Institute, 2018]
- Monograph of Marcel Breuer's work [Hyman, 2001]
- Monograph of Frank Lloyd Wright's Textile Block Houses [Moor, 2002]

The buildings listed in Table 1 are assumed to encompass the current possibilities, variety, and interest in architectural precast concrete from both design and fabrication standpoints within the set of outlined characteristics. The quantity and variety of buildings studied is intended to capture a magnitude of façade patterns and panel feature types, addressing both the "burden of going forward" and the "burden of persuasion" outlined by Taylor et al (2011) in *Meeting the Burden of Proof with Case-Study Research*. That study encouraged researchers to meet the highest level of persuasion, "beyond a reasonable doubt," which "demonstrates the applicability of theoretical model to scenarios outside of case data collected." In this research, façade patterns and panel feature types for each building in Table 1 are described. Modelling procedures and variables defining each type of pattern and panel feature are subsequently demonstrated. Then, a generalized framework for capturing a workflow for coordinating models of architectural precast concrete façades is established and applied to novel design proposals.

## 1.3 Background and current state

### *1.3.1 Façades and panelization*

In this research, the terms *façade*, *envelope*, and *skin* are used interchangeably to refer to the exterior surface of a building. It is worthwhile to note the multiple meanings of these words and the potential architectural implications. A "façade" refers to both a "face" and a "deceptive outward appearance." [Oxford English Dictionary, 2018] Furthermore, "envelope" and "skin" are each both verbs and nouns; enclosing structures and a series of actions leading to their production. Façades are critical to a buildings' character but remarkably complex in assembly. A detailed section cut through a building façade reveals that the architectural implication of envelopes/skins are in fact not paper-thin membranes, but are often thick systems of layers that make up the assembly of exterior walls and separate the interior from the exterior. Façades therefore create interior environments; critical to overall building performance. [Hegemann, 1929; Banham, 1969] Trubiano (2013) discusses the "spatialization" of building skins which "not only…advance the energy performance of the buildings they enclose, they also represent a new way of thinking about envelope for those desirous of surface depth and substance."

Dutton Architects (2013) provides a review of the history and insinuations of the pervasive focus on façade design, stressing two important points for consideration. The first point emphasizes the use of the word façade as the "face" of the building; "prior to modernism… this face was a separately designed architectural feature… [which] together with the façades of other buildings, created the identity of the street and public spaces." Whereas "modernism… focused on 'elevations'… exteriors were seen as the result of internal forces of spatial design and programmatic needs." The second point suggests that many of the building parameters such as size are often predicated by zoning, site, parking, and other client requirements leaving only the façade – a "sliver of fetishized architectural space" – left to design. Menzel (2012) has organized a collection of contemporary façade designs, demonstrating the trend to focus on performance, material, and unconventional patterning. The social importance yet spatially condensed aspects of façades are further elaborated in Zaera-Polo (2008), *The Politics of the Envelope.*

From the aspect of construction, Turgut (2007) describes six types of wall cladding systems based on Allen (2004), Brock (2005), Ochshorn (2003), and Quirouette (1982):

1. Stick Systems
2. Unit Systems
3. Unit and Mullion Systems
4. Panel Systems
5. Column Cover and Spandrel Systems
6. Structural Glazing Systems

Architectural precast concrete façades fall within the category of "panel systems." Illustrated in Figure 2, panel systems are characterized by large sized units attached to the buildings' superstructure with clips and/or anchors. Efficiency is obtained through standardization of panels across façades. This pattern that defines the bounds of individual pieces of precast is called *panelization.* The majority of precast (and other panel system) façades consist of either flat surfaces, but they may also be "ruled surfaces" or "developable surfaces." Patterns consist, for the most part, of triangular or quadrilateral panels. Each of these factors has an effect on manufacturing. This research aims to extend previous work on panelization [Pottman et al, 2007; Pottman et al, 2015] by formalizing knowledge for precast façades and establishing a workflow for coordinating digital models among project actors. This research will distinguish among the terms *panelization*, *panel boundary*, and *surface pattern* as each of these relate to *panel features.* Deeper understanding of the relationships between these terms, the geometries they represent in digital models, and the implications to corresponding physical components, will aid in confirmation of façade design intent and of details for fabrication within models for coordination.

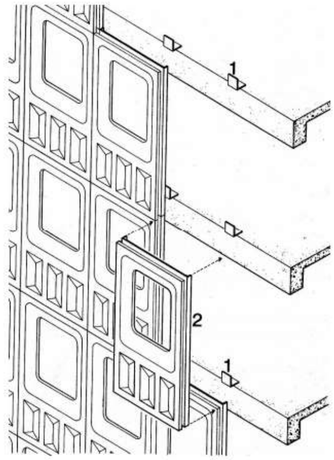



**Figure 2: Panel façade system from [Turgut, 2007]**

### *1.3.2 Project delivery and digital models*

In the Architecture Engineering Construction (AEC) industry, project delivery refers to the "handing over" of a set of building descriptions from the designers to those who will construct the building; namely, the construction manager. [Haltenhoff, 1978] In the conventional Design-Bid-Build process, this occurs only when these documents are "completed." While the intention of this process is to both remove liability from the design team and to emphasize competitive pricing, it also does not allow any feedback to the designers on the proposals' feasibility, budget, or schedule. In *Time, Cost, and Architecture*, George Heery – Atlanta architect credited with originating what would become known as construction management [Craig, 2013] – pondered the potential downside of this scenario:

> "…can something so intimately related to a building's design as the control of its cost and time of delivery be successfully separated from the design approach? It

> would seem clear that the two cannot be separated if that control is to be as effective as it can be... another view is that when there is strong control of cost and time, the design must suffer. This kind of logic cannot stand close scrutiny, but nonetheless many architects and others seem to feel that it is a fact. What, then, is the relationship between architectural design and construction management, and what should it be? [Heery, 1976]

Further blurring this line between architectural design and construction management is the ubiquitous use of digital modelling. Computer software tools such as *Rhinoceros (Rhino)*, *Revit*, *Grasshopper*, *Dynamo*, and others, permit even novice modelers to readily create digital objects. A main benefit of digital modelling is the ability to define and implement editable parametric variables and constraints. [Gerber, 2007; Davis, 2013] Such flexibility and the ability to quickly produce design alternatives during the design process allows for added design exploration and intentionality. Oxman (2017) has described the history, state, and impact of design computation and parametric design thinking, concluding that "sketching by code is not only a possibility, but promises to become a new norm of skill and knowledge." Similarly, Burry and Burry (2006) desire a process wherein, "digital spatial models take on the complex relationships inherent in a lattice of dependencies and variables [that] communicate the underlying structure and logical subtext of the architectural model." Benefits of digital modelling have become so widely known that Owners are now often requiring digital modelling and BIM (Building Information Modelling) processes and documents as part of their design and construction contracts. BIM is distinguished from other methods of digital modelling in that it includes additional non-model data and has the ability to support various design, procurement, fabrication, construction, and maintenance processes through various phases. [Eastman et al, 2011] A significant software learning curve and transformed workflow, however, means that reaping these benefits, particularly regarding coordination among different project actors and points-of-view, continues to be a challenge. [Kerosuoa, 2015]

An initial step of this research was to document the process of a precast fabricator during the shop drawing phase of their work, tracking a real project from receipt of a design intent model through the incorporation of industry-specific fabrication details. [Collins, 2016] Figure 3 shows a comparison of the design intent model (on the left) to the for-construction model (on the right) for the Shands Cancer Hospital by Flad Architects. The model from the design team shows that a base wall of the building is modeled as one piece with reveals to represent potential individual panels. When they received the project, the precast fabricator modeled each panel as distinct family types and instances using BIM software. A federated model of all panels for the project was then use to coordinate with other exterior wall assembly trades and components, explore construction sequencing, generate updatable shop drawings, generate updatable shop tickets, and calculate material quantities such as concrete volume and number and type of embeds.

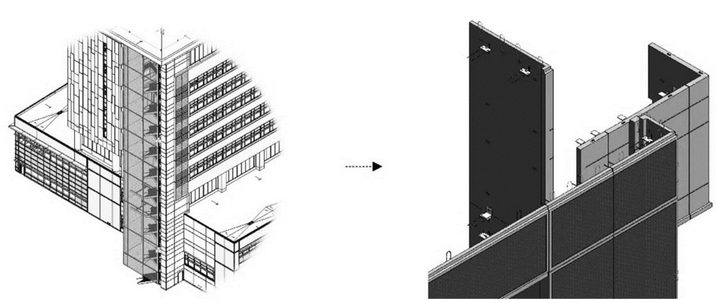
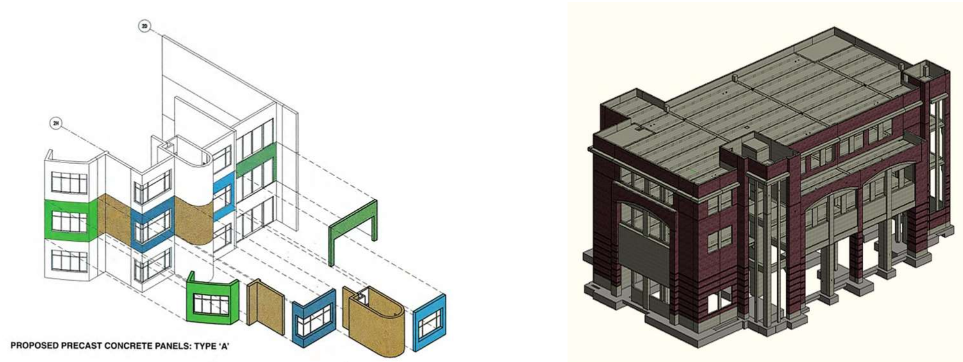


**Figure 3: Translating from design intent model to for-construction model**

There have been some attempts to capture precast concrete using digital models. Some of these systems, such as described in *Architecture in Precast Concrete,* suggest a "standardization" of precast elements. [Building and Construction Authority, 1999] An example illustration from that handbook is shown in Figure 4a. Others, such as *Edge for Revit* (a screenshot of which is shown in Figure 4b), are tailored for use by fabricators to remodel precast pieces. Alternatively, this research seeks to enable conversations and allow for direct exchanges of digital models of custom precast pieces between designers and fabricators during the design phase of a project.




a b

**Figure 4: Example previous precast coordination systems from [Building and Construction Authority, 1999 (a) and Edge for Revit, 2018 (b)]**

### *1.3.3 Standards and exchanges*

In order for various project actors, especially members of separate design and construction teams, to communicate regarding their design and construction tasks, they need to exchange information regarding building proposals. Translation of this information from one trade-specific software to another – from design intent model to for-construction model – has often taken place manually. To establish standards for the creation of component models, several industries have invested in defining parametric constraints pertinent to their trade. [Lee et al, 2006] The steel industry [American Institute of Steel Construction, 2013], the precast concrete industry [Sacks et al, 2004; Jeong et al, 2009; Belsky et al, 2014], and the masonry industry [Gentry and Collins, 2016; Gentry et al, 2016] have all begun to define how the architectural components that they provide are represented in digital models. This research is distinguished from previous work on standardizing modelling and data exchanges of concrete components in that it focuses on architectural precast concrete as opposed to the prior focus on structural precast concrete. A significant difference is the need to incorporate variable design intentions with specific fabrication requirements, whereas much of the previous work incorporated only the latter.

Eastman and Fereshetian (1994) describe the goal of these industry-based models to "define the semantic constructs underlying all data." They continue:

> The objective in all data and information modelling is to describe a universe of discourse (UoD). In most information models, the representation of the UoD consists of the creation of a structure of elements and connections, in a manner that allows the accurate expression of the user's (or some expert's) conception of some relevant portion of the world. The task of information modelling is to provide a sound basis for mapping between the portion of the world of interest and a representation of it that can be used as a specification for defining a database and/or application.

In consideration of the project goal of developing system that links models from designers and fabricators, this research builds upon the description of exchange models for precast concrete. [Eastman et al, 2009] The *Information Delivery Manual for Precast Concrete* identified 47 distinct model exchanges within precast concrete projects, including 11 for architectural precast. This research focuses on a series of three exchanges as highlighted in Figure 5. These are: [A_EM.5] Architectural Construction Model, [A_EM.7] Fabrication Model, and [A_EM.8] Architectural Review Model.

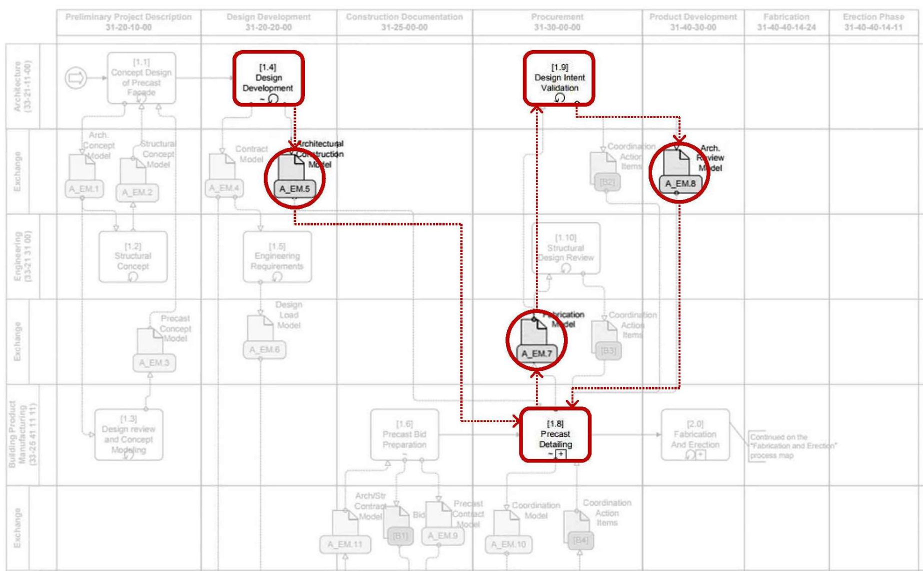



**Figure 5: Three critical exchanges highlighted within the exchange model of the Architectural Precast Process from [Eastman et al, 2009]**

The Architectural Construction Model consists of a “layout [of] precast elements.” The Fabrication Model references this layout to develop “precast piece detailing, descriptions of all connection details, finishes, joints, embeds, reinforcing, tensioning cable layout and block outs, pre-tensioned pieces, and lifting hooks for lifting and transporting.”

These details are provided to the design team via shop drawings. The loop in Figure 5 – back and forth between Fabrication Model and Architectural Review Model – depicts the traditional shop drawing review process. While the intent is for these exchanges to happen directly via digital model, in practice (and, as discussed, by contract), this does not often occur. An interpretation of the three highlighted exchanges in *Information Delivery Manual for Precast Concrete* model of the Architectural Precast Process is shown in Figure 6. Later, this process map will be referenced when discussing future state processes.

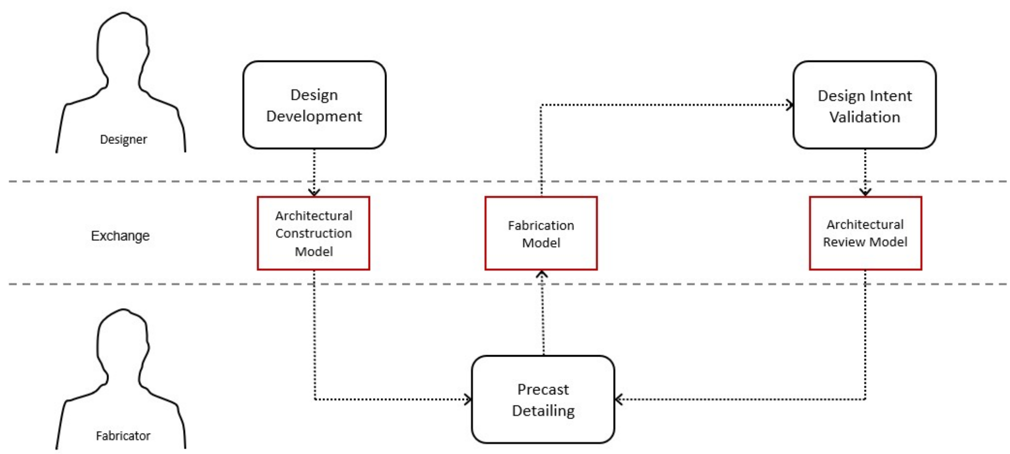



**Figure 6: Current state exchange model**

### *1.3.4 Meta models and mapping*

It is common practice among a variety of disciplines to verbally and visually describe and organize relationships, flows of information, and processes in order to communicate or improve upon such relationships, flows, and processes. In addition to the exchange model discussed in Section 1.3.3, other examples include ER (Entity-relationship) diagrams [Chen, 1977], UML (Unified Modelling Language) [Booch et al, 1999], and BPMN (Business Process Model and Notation) [White, 2004]. These methods of defining the explicit construction and rules for building models within a specific domain are also referred to as “meta models.” [Pidcock, 2003] In the same regard, one of the goals of this research is the ability to represent a wide variety of designs for architectural components within a generalized framework.

In the fields of Artificial Intelligence (AI) and Cognitive Science, a number of such schema for organizing knowledge have been developed since at least the mid-1980s. Several of these are discussed in Sembugamoorthy and Chandrasekaran (1986), Gero (1990), Yaner and Goel (2006), and Goel (2013). The goal of these diagrams is often the same; empower agents with the ability to reason and apply knowledge to new scenarios based on familiar previously encountered ones. [Goel, 2015] The contribution of such research is often twofold. First, modelling computational agents in the way that researchers initially believe humans think helps to develop better computational agents. Second, such modelling gives more reliable insight into how human thinking may or may not actually operate. Upon reflection, the steps repeat and both the process and the model are improved iteratively. These “expert systems” have long been developed to supply traditionally human-provided expertise, such as medical diagnosis. On the other hand, “human problem solving is often very complex, in that it involves multiple conflicting goals to be accomplished, rapidly changing environments, and rich social interactions.” [Thagard, 2005] Fioravanti et al (2017) further describe challenges associated with enabling agents to use architectural model data. They discuss the goal of advancing our current “human-computer interaction” to “human-intelligent computer co-operation” with the use of an additional layer of knowledge. The same is true of this research; initial digital models are produced in order to have conversations with fabricators regarding digital model operability. After receiving feedback, models and workflows are improved.

Previous work referenced in Section 1.3.2 [Collins, 2016] used process mapping to represent such workflows visually. The act of mapping the process in and of itself can help one to identify inefficiencies, problem areas, or opportunities for improvement in future work. [Gane and Haymaker, 2012] SysML (Systems Modelling Language) was used to record the precast fabricators' workflow through four phases – Estimating, Shop Drawings, Shop Tickets, and Fabrication. One particular aspect of a typical architectural precast concrete project that previous work identified as improvement-opportune is the current need for subcontractors to remodel architectural components; if the fabrication and assembly details could more directly inform the design intent model (and vice-versa) such a model could also serve as the for-construction model and eliminate the need for remodeling. Knowledge gained from that work has been incorporated into this research to inform process models and digital models representing both global and local perspectives.

Inspired by the DSSBF (Drawing Shape Structure Behavior Function) schema (illustrated in Figure 7), this research aims to connect similarly disparate cognitive and visual project descriptions. In DSSBF, "shapes and spatial relations are an intermediate abstraction between the structure and the drawing." [Yaner and Goel, 2006] These abstract spatial relations are composed of various lines and shapes which depict components and parameters. In this research, SBF will be defined through components and parameters at both global and local scales; via "scaffold models" and panel models or "frames." The connection between these two will be the precast "map." These maps are simultaneously often very important to the design team – they are significant to the overall aesthetic of the building – but, because they often involve expert knowledge, are also difficult for design team members to define. A variation of this schema will be presented later in discussion of future state processes. It is worth noting at this time, however, that the DSSBF is characteristically iterative at multiple levels in contrast to the mostly linear process depicted in the Architectural Precast Process, Figures 5 and 6.

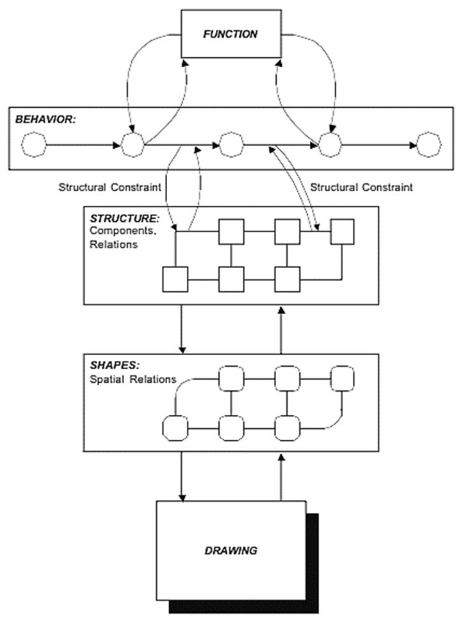



**Figure 7: DSSBF scheme from [Yaner and Goel, 2006]**

## 1.4 Research questions and methods

This research focuses on establishing a new framework for coordination among actors in architectural projects. The reason we need a new framework is that the current workflow is fragmented and underproductive. There is a disconnect between design and fabrication considerations; between designer and fabricator modes of working and representing buildings. Though, the solution is not as simple as developing separate "top-down" and "bottom-up" routines because design exploration also occurs at the local or component level, and fabricator coordination also occurs at the global or building level. This dissertation seeks to link these currently disparate "global" and "local" descriptions via parametric digital models. The main research question for this research is: How can data from parametric models representing global and local descriptions of architectural precast concrete façades be linked in order to bridge the currently disparate workflows and values of designers and fabricators, simultaneously enabling design exploration and incorporating fabrication details, during concept phases of work? This research is important because of a conundrum in the field of design computation; parametric modelling software is ubiquitous and user-friendly, allowing even novice modelers to readily create digital objects. However, intentionality and geometrical control of these objects – particularly regarding significant issues of component fabrication – is much more challenging. In addition to explicitly defining processes for creating digital models for both global and local representations, parametric "maps" – which elucidate and associate such descriptions and relationships – will be described for intentionally and precisely linking these distinct digital models to one another.

Five related sub-questions, which organize chapters two through six of this dissertation follow:

1. How have architectural precast concrete façades been coordinated?
2. What patterns do architectural precast concrete façades adopt?
3. How can fabricator expert knowledge effect panels?

4. How do these patterns and panels map to one another?
5. How does the proposed future state effect design and fabrication coordination?

Chapter 2 will present example precedent buildings to demonstrate the shifting role of the designer over the history of architectural precast concrete and the potential advantages of coordinated digital models for both design and fabrication.

Chapter 3 will discuss topics related to architectural precast concrete façades from a “global” perspective. This aspect of the work is sometimes referred to as “top-down,” or the designers’ point of view. As this research aspires to link and blur the boundary between designer and fabricator roles, these will instead be referred to as “global” descriptions. “Scaffold models” will be presented as a schema for defining key building relationships and parameters, and methods for modelling various surface patterns found in buildings in the list in Table 1 will be described. Christenson (2009) has accomplished similar work, parametrically modelling and flexing existing precedent buildings, concluding that “the use of parametric modelling in the study of existing architecture constitutes an opportunity to reveal possible semantic relationships within a subject work of architecture.”

Chapter 4 shifts to discuss architectural precast concrete panels from a “local” perspective; the so-called “bottom-up” or fabricator’s point of view. “Frames” for panels and features observed in example precedent buildings and industry documentation will be described. Knowledge gained from conversations with fabricators is documented, codified, and translated into constraints for digital models. Hollan et al (2000) define similar research methods as “cognitive ethnography,” aimed at discovering “not only… what people know, but… how they go about using what they know to do what they do.” Similarly, Keller and Keller (1996) describe an approach for investigating an “anthropology of knowledge,” asking; “What might the use of tools, this characteristically human way of doing things, tell us of the workings of the mind?” They continue:

> “Knowledge as a resource for production governs but does not determine practice; and practices, as they are enacted, may constitute a source of new information and may open prior knowledge to reproduction or transformation with further implications for ensuing practice… It is the emergent and synergistic character of human behavior… a person’s ability to conceive, act, asses, and reconceive in the process of making something… Emergence is a characteristic feature of the relation of knowledge and practice.”

Chapter 5 describes the process for linking digital models of the above global and local building descriptions. Documentation and models of precedent buildings will demonstrate the process of developing various parametric maps and their effect on design outcomes. Then, Chapter 6 will demonstrate the application of these processes through novel design proposals from a design studio in the Master of Architecture program in the School of Architecture at Georgia Tech. Finally, Chapter 7 will discuss and reflect upon the described future state framework, assumptions, protocols, and summarize contributions of the work.

# CHAPTER 2. DESIGN COORDINATION

This chapter explores four example precedent buildings from four different architects and different periods in the history of architectural precast concrete. These examples also demonstrate four different roles that the designers have undertaken the realization of building proposals. The intent is to contrast these evolving positions in typical architectural precast concrete building. The main question that this chapter explores is: How have architectural precast concrete façades been coordinated? What are the effects of this coordination (or lack thereof) on design and fabrication outcomes? The four buildings that will be discussed are:

1. Millard House, Pasadena, California, Frank Lloyd Wright, 1923
2. IBM Administrative, Laboratory, and Manufacturing Facility, Marcel Breuer and Robert F. Gatje, Boca Raton, Florida, 1972
3. Shands Cancer Hospital, Gainesville, Florida, Flad Architects, 2017
4. Perot Museum of Nature and Science, Dallas, Texas, Morphosis Architects, 2012

As described by Schon and Wiggins (1992), “designing [is] a kind of experimentation that consists [of] reflective 'conversation[s]' with the materials of a design situation.” These four examples projects demonstrate a variety of methods designers have used to engage with materiality and fabricators during the process of design and construction, both with and without the use of digital models.

## 2.1 Millard House

While it could be argued that the Textile Block Houses, the four residences designed and built by Frank Lloyd Wright in the Los Angeles, California area in the 1920’s [Moor, 2002], are more closely related to masonry than to architectural precast concrete, they are included in this research for three reasons: the proportions and custom design of the precast pieces themselves, Wright’s attitude toward the material, and the fabrication approach.

First, the proportions of the Textile Block House panels, though they are smaller in size (to allow them to be carried by hand on site), are nearer to façade panels; a ratio wherein the height and width are much larger than the thickness. In addition, the pieces were custom casts for each house rather than standard reused molds typical of masonry. Second, prior to designing these homes, Wright referred to concrete block as “[t]he cheapest (and ugliest) thing in the building world…[a] gutter-rat.” [Wright, 1932] After its completion, Wright said of Millard House that he “would rather have built this little house than St. Peter's in Rome.” This suggests quite a change of opinion after having worked with the material. Wright seemed to have acknowledge the expressive potential of the material after working with it, and, over time, developed knowledge of how to balance design aspirations and with issues of construction. Finally, the houses are included because of Wright’s approach for fabrication and assembly of the Textile Block Houses. Many issues arose from this “unique and untested” system, well-documented by Losch (2016). However, venerable design ambition and experimentation – and even the notion that “if all the complexity and required precision could be worked out in advance on the drawing board and factory, then assembly would be simple” – make these homes relevant to this work.

Two specific issues arose during design and construction of Millard House that are significant; panel size and joint tolerance. Losch discusses both of these issues. “Initially [Wright] specified a unit size 24" by 24", but had to reduce it to 16" square so the blocks would be light enough to lift.” And, furthermore, “the requirement for tight joints with no dimensional tolerance had the opposite effect to that desired, making the site construction process significantly more labor and skill intensive.” (Contrary to the goal of using unskilled labor to make the houses more affordable.)

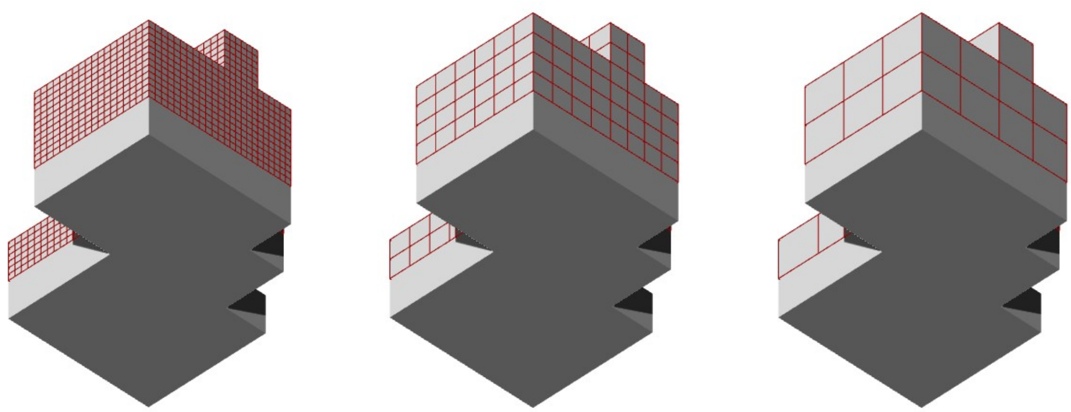


**Figure 8: Millard mass with varying grids**

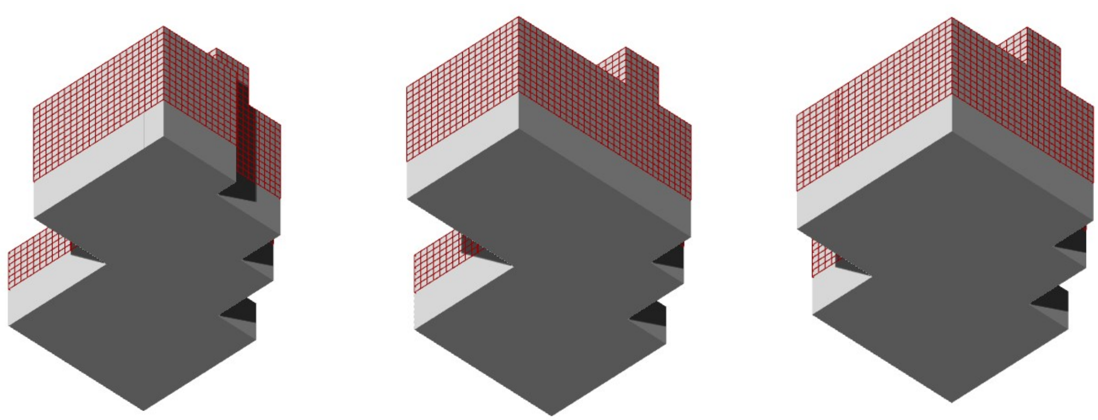


**Figure 9: Grid on varying Millard masses**

A digital model of the massing of Millard House is created. Using visual scripting, parametric patterns representing individual panels can be applied to each surface (or parts of surfaces) of the mass. As demonstrated in Figure 8, the scale of the pattern – and, therefore, the size of the panels – can be "flexed." In fact, shown in Figure 9 the mass can also be flexed and the panels maintain coordination. Tracking such changes in panel size or mass dimensions is extremely cumbersome by hand. In addition, the scripted model is also capable of much more complex patterns; the grid shown on the above model is used for demonstration purposes. The actual pattern on Millard is more complex with "half panels" at the edges of each surface. A script can be written, illustrated in Figures 10 and 11, to more closely represent the Millard pattern. This model takes advantage of a genetic algorithm function available in *Grasshopper* software to solve for a given "optimum" panel size.

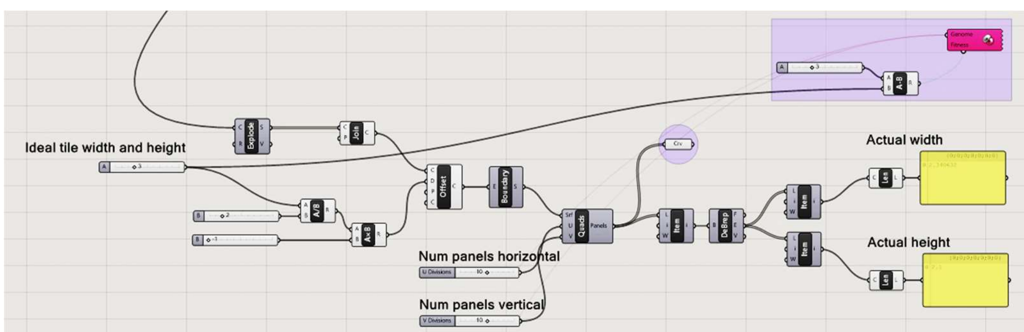



**Figure 10: Millard surface pattern optimization script**

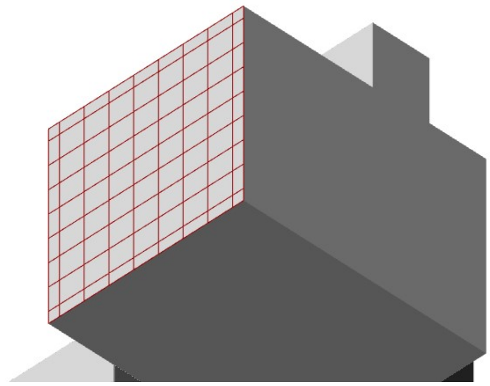


**Figure 11: Millard surface pattern optimization model**

Methods for linking models of building masses and panels among various surface patterns in digital models will be discussed in Chapter 3. This example gives a glimpse into the possibilities – especially regarding design and fabrication coordination – offered by linking surface patterns and building massing of digital models. Beyond that, this example also serves to demonstrate that lack of coordination has a negative impact on fabrication. While a digital model is capable coordinating various scales and complex geometrical issues, there are still others issues – such as proper tolerance between elements – which require an additional level of knowledge that is often unknown to the designer. Linked global and local models will have the ability to incorporate such knowledge while also allowing design flexibility.

## 2.2 IBM Administrative, Laboratory, and Manufacturing Facility

As mentioned, over the course of his long and successful career, Marcel Breuer became a master of precast concrete; particularly with regards to its use in expressive building façades. His designs are also significant to this research in that he was likewise simultaneously considering global and local building descriptions; “the thinking about form and detail is all part of the same process: the design. I am as much interested in the smallest detail as in the whole structure." [Breuer, 1962]

With Breuer’s success and extensive use of precast façades, Gatje indicates that a “language” was formed:

> “It was perfectly possible for each partner and many of the designers to follow and elaborate upon the precedents set by Breuer. Each of us contributed something new and different… but our interpretation was close enough to that of the master that all of the buildings… are Breuer buildings… Each solution differed slightly from its predecessor as we learned from experience and were prodded by [Breuer’s] constant search and invention.”

It is interesting, then, to note when disparities occur:

> “Ham [a partner in Breuer’s office] had been working on an assembly plant in Belgium [Torin Corporation] when the engineers of Schokbeton, which was to do the precasting, suggested projecting fins as sun-shades and stiffeners on the tall factory panels. The beautiful, asymmetric positive patterns that resulted were startlingly different from the negative hollows with which we had become familiar.”

A similar scenario – fabricators and designers working together to achieve innovative solutions for panel issues – was noted during IBM Administrative, Laboratory, and Manufacturing Facility:

"When I [Gatje] was working on the three-story laboratory wings in Florida, the engineers suggested a number of economies that derived from the very advanced precast industry of the area. First, they proposed that one panel cover and support both of the upper two stories. Then they asked for a central rib in the middle of each eight-foot panel to stiffen it and to receive the load of long-span Ts arriving at each floor level. Without the window-shading canopies that we added, this panel would have looked remarkably like the many tilt-up factory panels in the neighborhood. With the intersecting ribs, they look somewhat like a double crusader's cross and, in the long curving lines of the Y-shaped buildings, play optical tricks under the hot Florida sun."

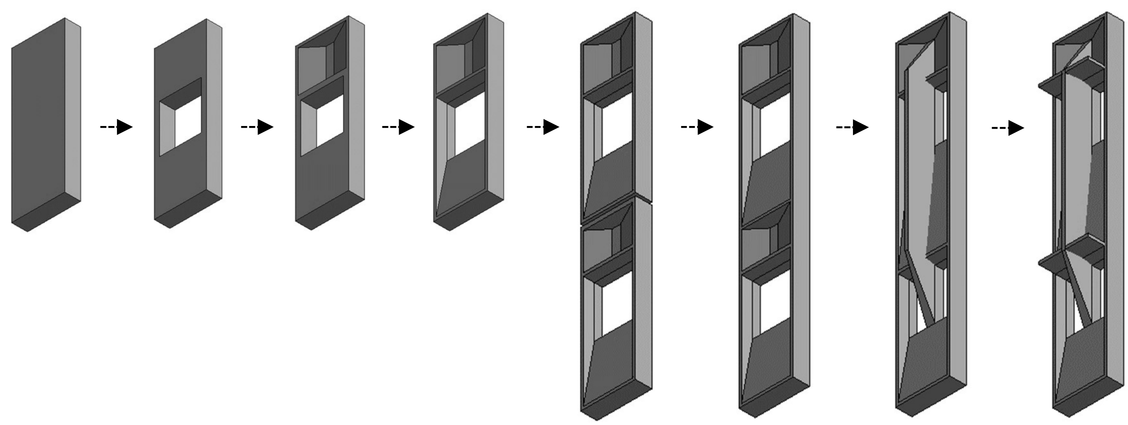


**Figure 12: Combining features for the IBM Boca Raton panel**

A digital model of IBM Administrative, Laboratory, and Manufacturing Facility panels is created. Using parametric geometry, features of the panel can be combined and flexed to produce a wide variety of options. Methods for producing such panel families and variations will be discussed in Chapter 4. The model is used to demonstrate a hypothetical design process, indicated in Figure 12, wherein the panel evolves from flat, to opening, to incorporation of facets, facets linked to opening, the suggestion of combining panels to span two stories, the structural rib, and window shades. Panel models with predefined parametric features can enable these conversations among designers and fabricators; interaction that Breuer's office and subsequent building designs benefitted from over time and experience. Such models could also serve as more accurate representations for additional routines such as daylight and shadow studies, energy and building performance simulation, and automated detailing.

Methods for linking these panels to diagrams of building masses – called "scaffolds models" – will be discussed in Chapter 5. An example linked model for IBM Boca Raton is shown in Figure 13.

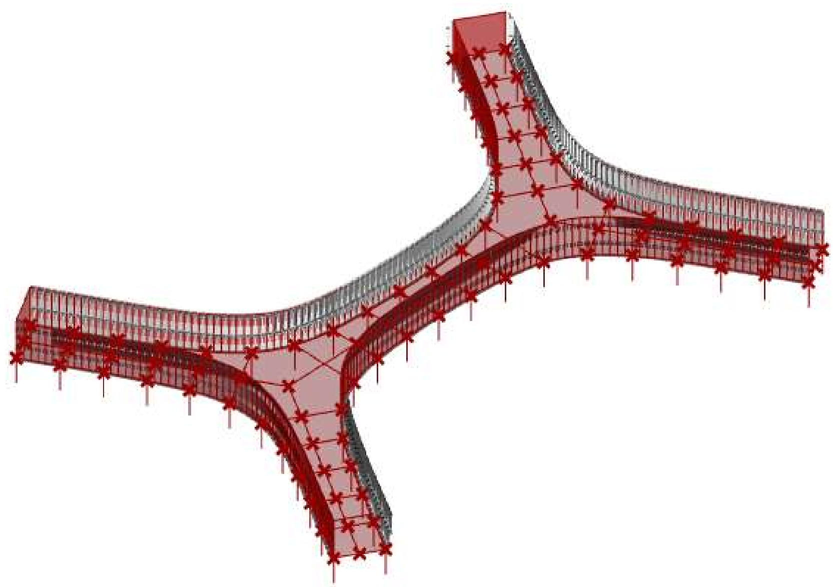


**Figure 13: Linking panels and mass model for IBM Boca Raton**

## 2.3 Shands Cancer Hospital

As discussed, the typical Design-Bid-Build process – regardless of whether it removes liability from the design team or purportedly emphasizes competitive pricing – does not allow for any feedback to the design team on the proposals' feasibility, budget, or schedule. Current standard contract forms and procedures in the typical Design-Bid-Build process state this in black and white; the designer is not required to provide the means and methods of the fabrication, but a general direction for the design intent at which point various contractors fill in the gaps. However, George Heery continued to ponder the downsides of this arrangement, stating "design intent has to do with the desired outcome, not the means by which it is achieved, however, as any designer knows, the design process can heavily influence that outcome." Furthermore:

> "many would point out, and with some validity, that the evolution of construction management as a profession, or definable professional service, has taken place within and because of a management void left by the architectural and engineering professions." [Heery, 1976]

The filling of this "management void" by:

> "these [new Construction Manager] specialists – often trained as architects or professional engineers themselves – was meant to streamline the building process by making others accountable for aspects of construction, changing costs of materials, managing leads times for materials or equipment and making substitutions, or even

> challenging design decisions made in the construction documents, but it did little to increase trust between owner, architect and contractor – in fact often it made the building process more contentious."

This lack of trust is one contributing factor in the disconnect between designer and fabricator modes of working and depicting projects. Other factors include a software learning curve and often significant transformations to existing workflows. Not too long ago, contractors who took on the additional technical and personnel expenses that BIM incorporation requires had a competitive advantage to those who could or would not. In the introduction to SHoP Architects monograph [SHoP, 2012], Nobel concurs that "concerns [which] impede [a more] widespread implementations of BIM are…primarily [due to] a perceived inability of subcontractors to adopt or work with… technology." However, "resistance disappears once the efficiencies accruing to the bottom line are evident." Indeed, over time, the AEC industry as well as the owners funding their buildings have accepted – if not begun to rely upon and require – BIM so widely that those contractors who can't or won't evolve their "traditional" processes are in danger of being left behind.

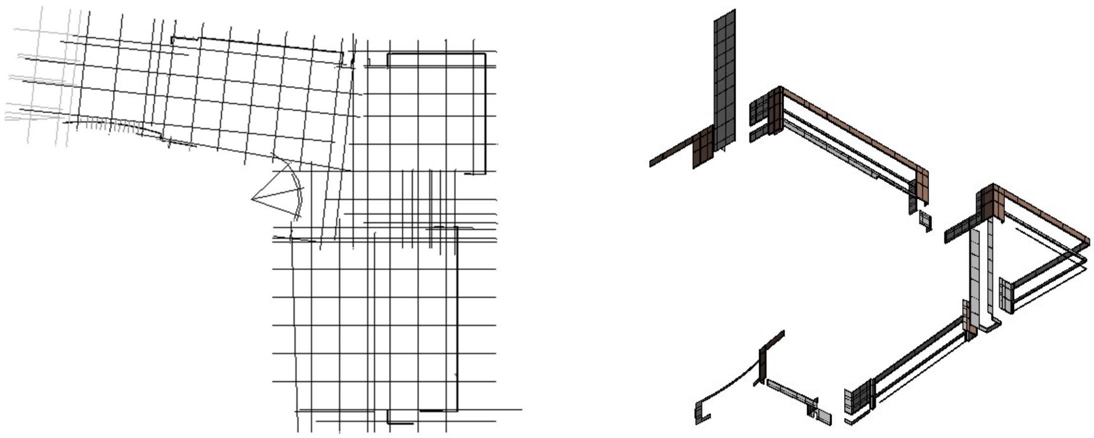


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**Figure 14: Shands Cancer Hospital scaffold (a) and federated model (b)**

In 2014, Castone Corporation (Castone) contacted Georgia Tech's Digital Building Lab to start a conversation about the possibilities of incorporating digital modelling into their existing workflow. The building that served as the trial for that project was University of Florida Health Shands Cancer Hospital (Shands) by Flad Architects. This work was previously published. [Collins, 2016]. As discussed therein, "the primary goal for [that work was]… to aid Castone in building a digital model of the architectural precast concrete pieces… through the use of the software program *Autodesk Revit*." Additional benefits of interest included clash detection, shop drawings and shop tickets production, and material take-offs.

Described in Collins (2016), "Castone used a 'scaffold' of lines representing the building superstructure column grid and edge of slab to locate each piece." A view of this "scaffold" is shown in Figure 14a (shown in plan view because visibility of grids in *Revit* 3D views is not currently supported). Parametric families of panels were created. A sample is shown in Figure 15. As each piece was instantiated (wall panel varieties are shown in Figure 14b), they were federated to the Contraction Manager's file for coordination with the building structure and other exterior components and materials. Views of the coordination model are shown in Figure 16. It is noted that in one particular occasion that:

> "viewing the federated model revealed a clash of panel embeds with a column. During the coordination phase, the embed could easily be moved. Without the use of the digital model in this way, it would have been far less likely to catch this conflict, leading to costly adjustments in the field long after the pieces had already been manufactured." [Collins, 2016]

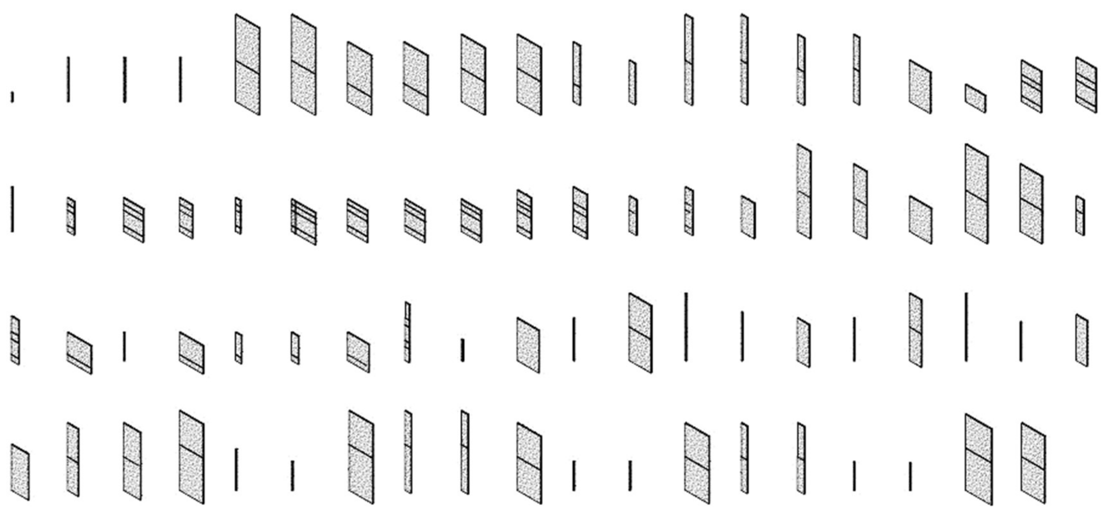
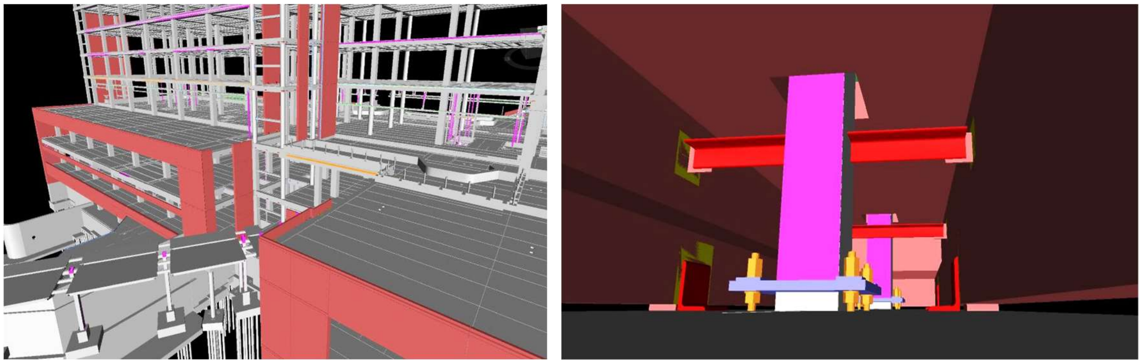


**Figure 15: Shands Cancer Hospital wall panel family**



a b

**Figure 16: Shands Cancer Hospital coordination model views**

The Shands project had 313 pieces of precast requiring 56 different digital model families. Families are distinguished by shape type: spandrel, walls panel, wall cap, radius panel, soffit return, etc. [Farr, 2015] The model was also used "to create spreadsheets for material takeoffs (weight and cubic feet per panel), calculate square feet of brick to purchase, hardware lists and totals, and rebar schedules." This example demonstrates that, while parametric digital models do help to achieve precise geometry and collection of various sorts of data for fabrication and construction activities, coordination among various actors is still critical. This research endeavors to allow such coordination to occur earlier and more directly in the design process. Moreover, advancing functionality of the scaffold model concept is key.

## 2.4 Perot Museum of Nature and Science

An emerging technique in which design teams and owners are supplementing the design phase with industry knowledge is called "design assist," defined by the AIA as "the procurement method by which, prior to completion of design… a contractor provides design assistance to the architect or engineer." [Hart, 2007] Engaging trades in such conversations early in the design phases can give the design team access to industry knowledge – for example, parameters effecting shop tickets and therefore the outcome of the precast pieces – during the design phases. One project that experimented with design assist is the Perot Museum by Morphosis Architects (Morphosis). Architectural precast concrete façade panels for the project were detailed and fabricated by Gate Precast Company (Gate).

The design for the façade of the Perot Museum involves a complex layering of patterns and textures. Mo Wright, marketing director at Gate, describes implementing the design assist process:

> "At the time we were brought in, Morphosis was exploring ideas but hadn't settled on a particular concept… This was ideal from our point of view. As we showed them what was possible with precast techniques, they responded with design ideas that might not have occurred to them otherwise. In turn, we were able to make suggestions that helped the final design to be more cost-effective." [Stocking, 2017]

Further discussions with Gate personnel (documented in Appendix C) revealed the difficulty in defining the geometric limitations of all panel features in order to constrain digital models to representations of panels that are "constructible."

> "Well, that's going to be something that's very, very hard to define. It varies so much by plant, by location, by how thick the panels are… and obviously [the] size of the job we're working on… we looked at [Perot] and initially set it this way and then a couple of small things changed in the design of the structure. And now the panel is no longer [the same]. We had to make them two inches thicker or wider or moved the profiles to adjust this and each one of our plants and every precast manufacturer has a different capacity… we can give you some parameters, some general parameters. Shipping typically rules the roost… what can you get up the road?"

Morphosis and Gate were able to use digital models to coordinate design concepts and fabrication constraints. Further documentation of this workflow can be found in [Dosher, 2012]. It is the goal of this research to enrich similar conversations and streamline exchanges of digital models between designers and fabricators even earlier in the process. Such practice could embed design intent models with fabrication knowledge that allows them to mature directly into models for construction and expedite much of the back and forth of traditional work flows.

This chapter has discussed four example precedent buildings from four different architects and different periods in the history of architectural precast concrete. For each of these projects, the designers have undertaken different roles towards the realization of building proposals. These roles have also differed in engagement with precast as a material and use of expert knowledge to inform design. Example digital models have been used to show the potential benefits of such models for project coordination. Fabricator input would clearly have benefitted proposals for unconventional designs, such as those for the Textile Block Houses, just as it did for many Breuer projects. Chapter 3 will discuss design parameters and the creation of digital models from the global perspective.

# CHAPTER 3. FAÇADE PATTERNS AND COMPOSITION

A review of precast buildings described in Section 1.2 reveals a desire for unconventional designs. We must ask, how will a system that links designer and fabricator models be able to accommodate such expressive proposals? In that regard, the main question that this chapter seeks to answer is: What patterns do architectural precast concrete façades adopt? We must also consider: how do our tools and methods of practice effect design outcomes? How are building surface patterns defined? What are the parameters? These questions emanate from a complex dynamic of software and user, capability (of software) and ability (of user), and explicit and tactic knowledge. Bernal et al (2015) categorize such "role[s] of computational support for designers in action." Critical to this work is degree of design expertise [Lawson and Dorst, 2009; Bernal, 2016] and the "ill-structured" [Cross, 2001] or "wicked" [Rittel and Webber, 1973] nature of design. Further complicating these matters, the role of computation in design – both technically and cognitively [Menges and Ahlquist, 2011] – continues to be explored and debated. Nevertheless, this research seeks to provide customizable parametric model definitions with which designers and fabricators can readily interact, explore possibilities, and validate intent.

## 3.1 Scaffold models

It is posited that most buildings are comprised of key systems – shape, grid, levels, and surfaces – and that defining the parameters and relationships between each of these systems describes the basic structure for a given building. Additional subsystems can then

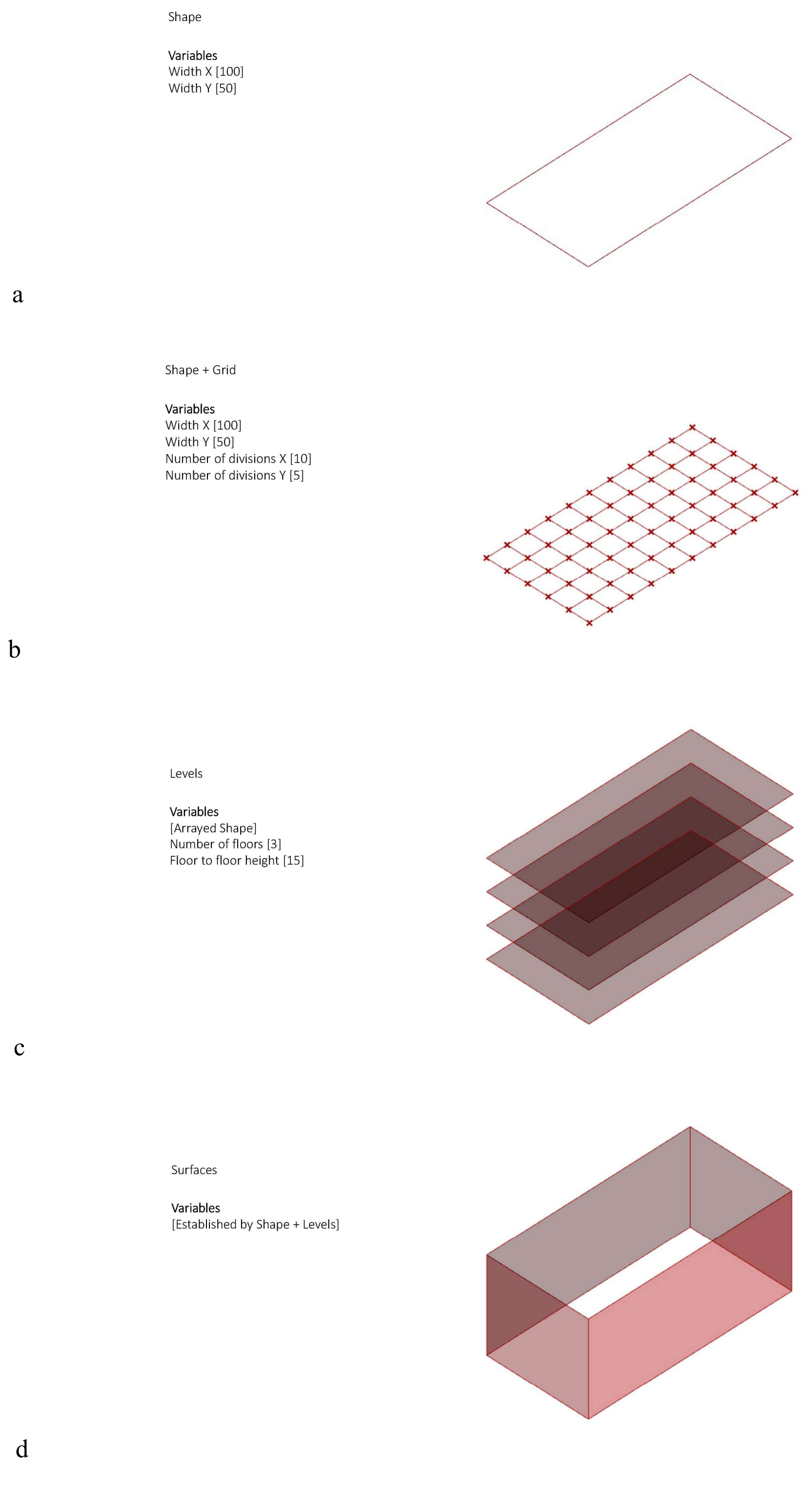



**Figure 17: Modelling example scaffold – shape (a), shape + grid (b), levels (c) and surfaces (d)**

be associated or "hung" onto each of the main components, corresponding to Burry and Burry's appeal for models that communicate buildings' underlying structure. As a simple example, Figure 17 indicates how defining the shape (a), grid (b), levels (c), and surfaces (d) of a simple rectilinear mass provides basic panel boundaries for the exterior surfaces of the building. There are six parameters that control this model: width of rectangular shape in the x direction, width of the rectangular shape in the y direction, number of divisions in the x direction, number of divisions in the y direction, number of floors, and floor-to-floor height.

Shown in Figure 18, this data can combine to define basic panel boundaries. It will be shown later how to apply panels to individual boundaries. Beforehand, there are several implications for the panels in this model that need to be addressed in order to advance this from a simplistic diagram to a more realistic representation of the relationship between a buildings' structure and architectural precast concrete panels. First, the model suggests that the centerline of the column grid, the edge of the floor slab, and the back side of the panels are all in the same plane. For constructability as well as design issues, this is very unlikely. Second, the top of the panels at the upper level and the bottom of the panels at the lower level each align with the top of floor slab height. This is also unlikely due to thicknesses of materials and the fact that the panels will extend beyond these limits to close the building. Therefore, depicted in Figure 19, a series of further modelling operations are undertaken to define four additional parameters: dimension from column centerline to edge of slab (Figure 19a), dimension from edge of slab to surface (Figure 19b – what this surface represents will be discussed later), and dimensions from upper level to top of surface and from lower level to bottom of surface (Figure 19c). A detailed description of the script for this model is provided in Appendix B.

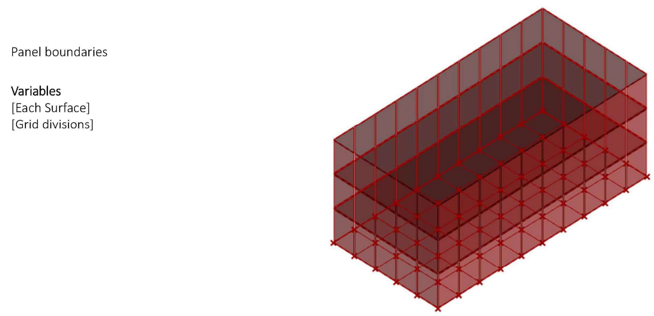



**Figure 18: Example scaffold model defining panel boundaries**

This scaffold may be thought of as a behavioral model; it shows conceptually how the building behaves based on certain functional qualities that may come from the client or designer such as project goals, size, spatial organization, etc. Similar models have been called "generic abstractions" [Dogan and Nersessian, 2010] or "mental models" [Johnson-Laird, 1983]. With such digital models and their formal generation documented, a designer can interact with the code, strategically analyzing variations in pursuit of additional project goals. This model provides a visual diagrammatic form which represents the building schema in the designer's mind. Variables correspond to and represent the Architectural Construction Model exchange highlighted in Figure 5.

### 3.2 Relation to structural frame

With these new surfaces defined, we can look again at the relationship between the buildings’ structure and panel boundaries. There are three main categories of this relationship:

- Projecting the structural grid to the surface (shown in Figure 20)
- Transposing the structural grid variables to the surface (shown in Figure 21)
- No relationship (defined on its own; example shown in Figure 22)

When projecting the structural grid to the surface, there are additional corner panels that correlate to the offset dimension between the structural grid and the surface. Therefore, while the majority of the indicated joints between panels express the structure of the building, these end pieces are anomalies. Furthermore, there is a question of how these pieces are supported. While transposing the structural grid variables to the surface addresses the latter issue, the panel proportions and locations are not “true” to the buildings’ structural logic. Of course, it is also possible for the surface pattern to have an entirely different pattern than the one suggested by the structural grid. Still further, the surface pattern may be derived from a mathematical operation using the variables of the structural grid (two panels per structural bay, for example) or the pattern may be a combination of these relationships (a random pattern in the horizonal direction while following the cadence of the structural grid vertically, for example). These topics will be discussed further in Chapter 5.

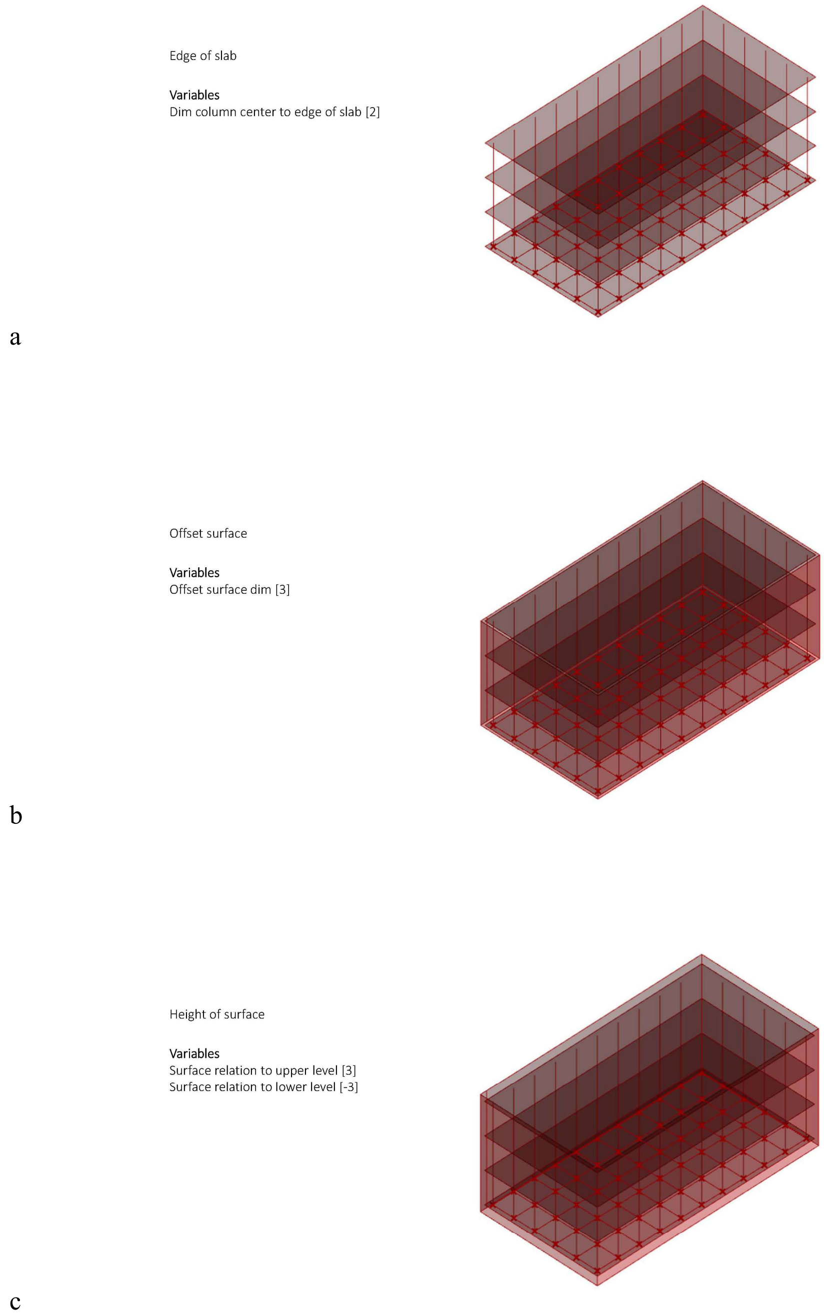



**Figure 19: Additional modelling of example scaffold – edge of slab (a), offset surface (b), and height of surface (c)**

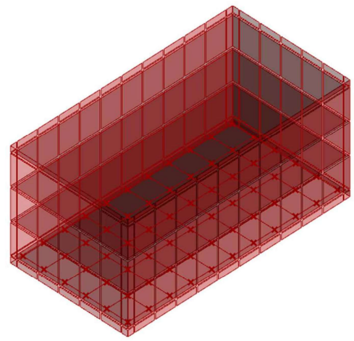


**Figure 20: Projecting the structural grid to the surface**

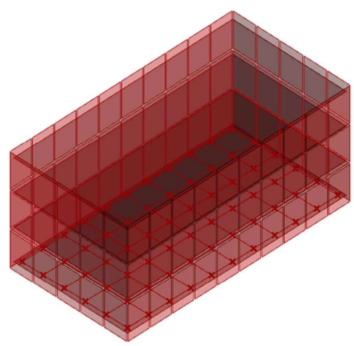


**Figure 21: Transposing the structural grid variables to the surface**

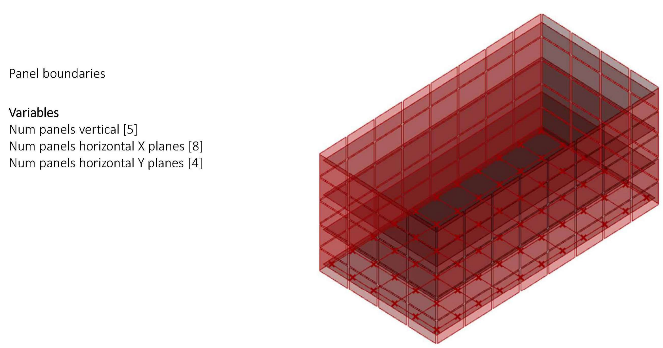



**Figure 22: Demonstrating no relationship between the structural grid variables and the surface**

Three additional questions also arise which will be discussed further in the next section and shown through models of precedent buildings in Chapter 5 and trial studies in Chapter 6. Examples are shown here to demonstrate the continued functionality and flexibility of the scaffold model concept notwithstanding:

- What if the building structure is not the typical vertical columns? (Example shown in Figure 23)
- What if the shape of the building is not a rectangle? (Example shown in Figure 24)
- What if the surface pattern is not a grid? (Examples shown in Figure 25)

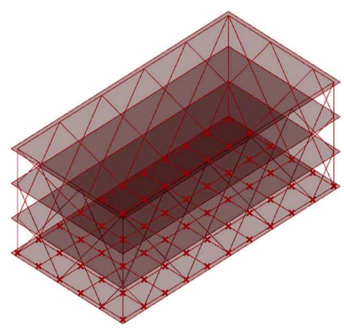


**Figure 23: Example non-vertical-column building structure**

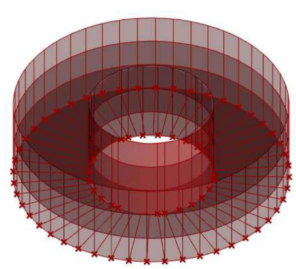


**Figure 24: Example non-rectangular building**

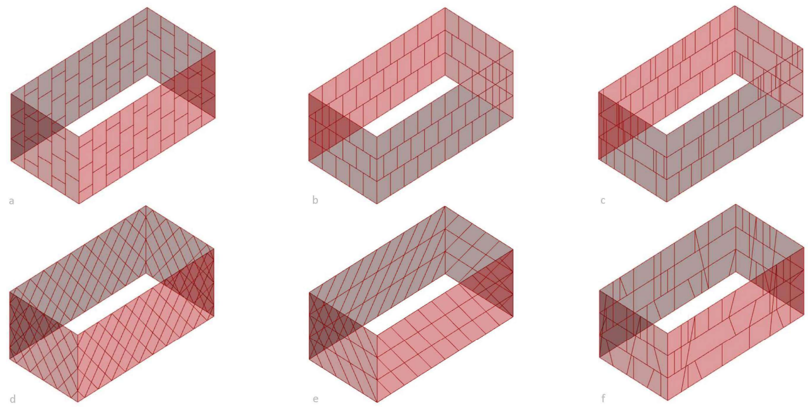


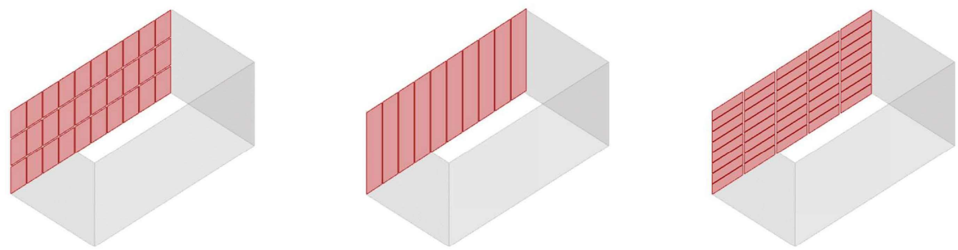

**Figure 25: Example non-grid surface patterns**

### 3.3 Surface pattern types and examples

Within our list of precedent buildings with architectural precast concrete façades, there are four major types of surface patterns. Each of these as well as example buildings demonstrating these patterns will be discussed:

1. Grid (regular or irregular)
2. Running bond (horizontal or vertical)
3. Irregular quads
4. Diagonal

### *3.3.1 Regular grid*



Variables
Num panels vertical [5]
Num panels horizontal [10]

Variables
Num panels vertical [1]
Num panels horizontal [10]

Variables
Num panels vertical [8]
Num panels horizontal [5]

**Figure 26: Example regular grid patterns and variables**

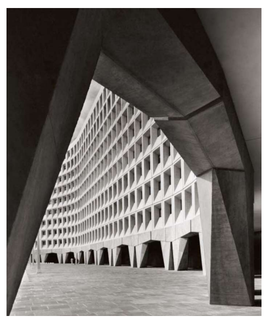
Regular grid is by far the most widely used pattern. Among others, we see this pattern in 150 Rouse Boulevard by Digsau (Figure 27a), Airea by VIDARQ (Figure 27b), California State University San Bernardino College of Education by LPA (Figure 27c), CEDETEC by LANDA Arquitectos (Figure 27d), Department of Housing and Urban Development Headquarters by Marcel Breuer, Nolen-Swinburne and Associates, and Herbert Beckhard (Figure 27e), Kauffman Center for the Performing Arts by Safdie Architects and BNIM (Figure 27f), Maritime and Seafood Industry Museum by H3 Hardy Collaboration Architecture (Figure 27g), and Philadelphia Police Department Headquarters (Roundhouse) by Geddes, Brecher, Qualls and Cunningham (Figure 27h). After isolation of a surface, there are two parameters that control a regular grid: number of panels vertically and number of panels horizontally. All of Frank Lloyd Wright's Textile Block Houses have this pattern. Many Marcel Breuer buildings employ a regular grid pattern, reinforcing the structural logic and repetition of many of his buildings. On the other hand, the regular grid can be used to contrast an irregular form, such as in Zaha Hadid Architects' Pierresvives or Kauffman Center for the Performing Arts by Safdie Architects and BNIM.

a

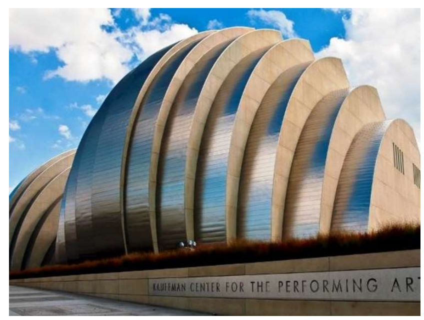
b

c

d



e




f

g

h

**Figure 27: Example regular grid patterns in precedent buildings ***

* For precedent building image references, see Appendix A.

### 3.3.2 *Irregular grid*

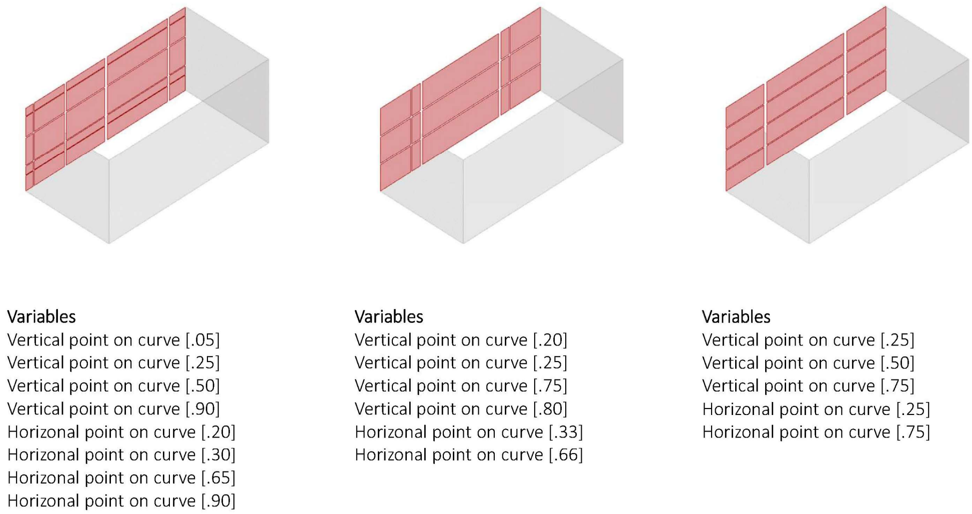
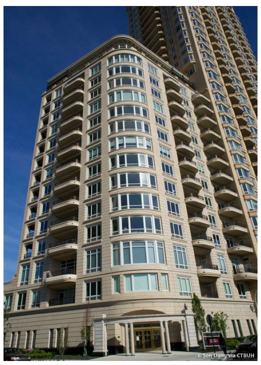



**Figure 28: Example irregular grid patterns and variables**

There are a number of ways that one could create models for irregular grids. The basic concept is that the vertical and horizontal lines are continuous for the extent of the surface. Lines could be randomly place or have a repeating syncopation. In a number of the example precedent buildings, “irregular” grids actually have a pattern, similar to classical A-B-A or other sets of proportions. Such façade lines could also be related to the structural grid, interior partitions, or other building organizational logic. We see irregular grids in Adtran Corporate Headquarters by Cooper Carry (Figure 29a), American Pharmacists Association Headquarters by Hartman-Cox Architects (Figure 29b), Lincoln Park 2550 by Lucien Lagrange Studio (Figure 29c), and The Century by Robert A.M Stern Architects (Figure 29d).

a

b



c


d

**Figure 29: Example irregular grid patterns in precedent buildings ***

For the examples shown in Figure 28, vertical and horizontal “points on curves” define such proportions in each respective direction. The number of variables is therefore related to the number of lines. If the pattern repeated or was symmetrical across the façade, the number of variables could be reduced.

### *3.3.3 Horizontal running bond*

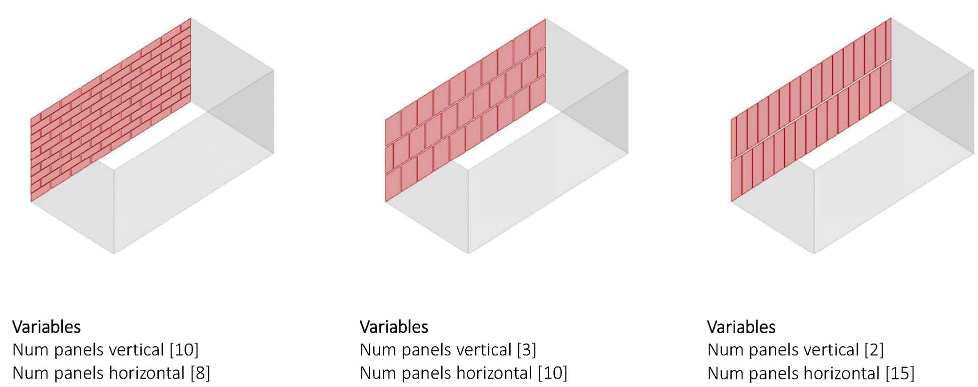



**Figure 30: Example horizontal running bond patterns and variables**

The running bond patterns are controlled by two parameters: number of panels vertically and number of panels horizontally. Horizontal running bond is seen in Atlanta Central Public Library by Marcel Breuer and Hamilton P. Smith and Stevens and Wilkinson (Figure 31a), U.S. Embassy London by Eero Saarinen (Figure 31b), and Waldorf Astoria Chicago by Lucien Lagrange Studio (Figure 31c). In the Atlanta Central Public Library and U.S. Embassy London, each of the running bond areas is an individual panel. In the Waldorf Astoria Chicago, running bond is expressed via reveals in the panel surfaces. The modelling differences for these two approaches will be discussed in Chapter 5.

a b c

**Figure 31: Example horizontal running bond patterns in precedent buildings ***

### *3.3.4 Vertical running bond*

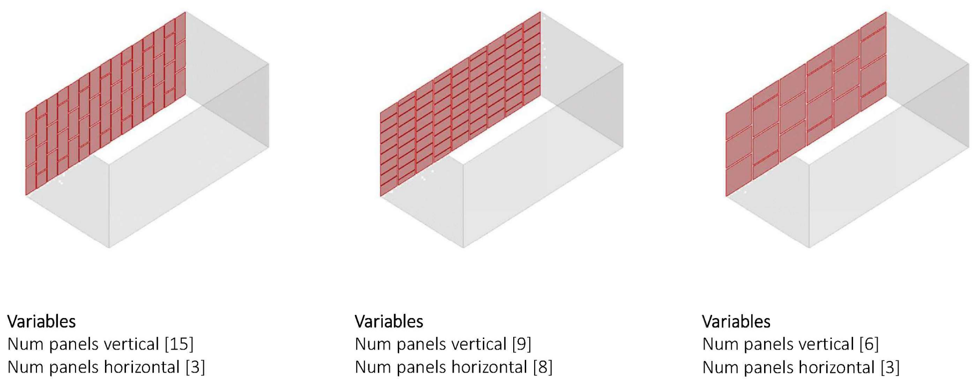



**Figure 32: Example vertical running bond patterns and variables**

Vertical running bond is seen in 1200 Intrepid by Bjarke Ingels Group (Figure 33a), and Teen Living Programs (Belfort House) by Hartshorne Plunkard Architecture (Figure 33b). Patterns for vertical running bond are controlled by the same two parameters as horizonal running bond, and also similarly, these two examples demonstrate two different approaches to the pattern; defining panels and defining reveals on panel surfaces. (Again, discussed in Chapter 5.)

a b

**Figure 33: Example vertical running bond patterns in precedent buildings ***

### *3.3.5 Irregular quads*

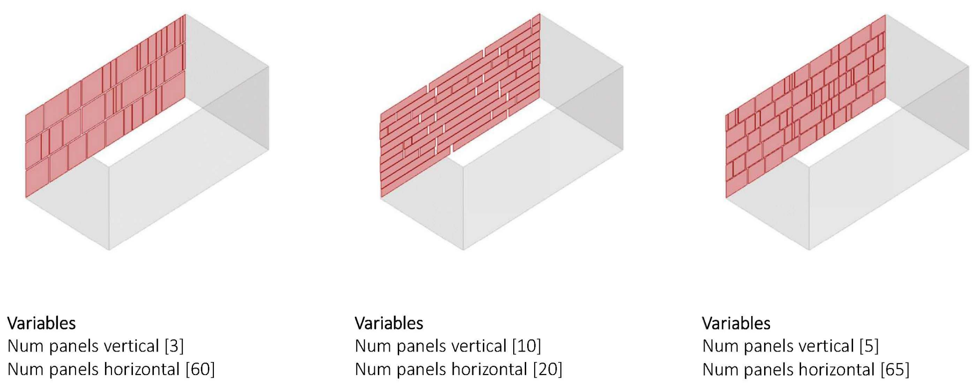
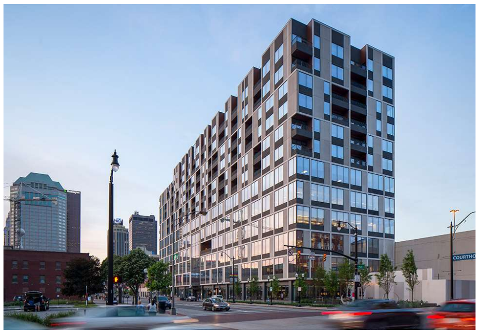
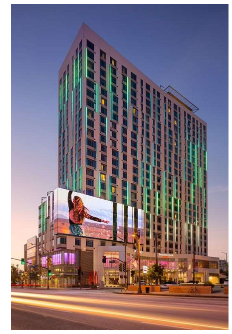
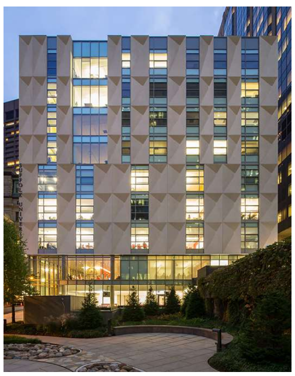



**Figure 34: Example irregular quad patterns and variables**

a b c

d e f

**Figure 35: Example irregular quad patterns in precedent buildings ***

The irregular quad patterns are widely used in contemporary examples; 250 High by NBBJ (Figure 35a), Dior Miami Façade by Barbaritobancel Architectes (Figure 35b), L.A. Marriott by GBD Architects (Figure 35c), Suffolk University 20 Somerset Street by NBBJ (Figure 35d), The Ohio State University South Campus Chiller Plant by Ross Barney Architects (Figure 35e), and University of Chicago Campus North Residential Commons by Studio Gang (Figure 35f) to name a few. The irregular quad pattern is mainly controlled by two parameters – number of panels vertically and number of panels horizontally – however, there is an additional input option; "seed." The pattern of irregular quad is "random." ("Random" is in quotes because there is actually a defined algorithm that defines the pattern output.) The “seed” variable permits the user to flex the distribution of random panels, allowing for some control of the surface pattern. Furthermore, such random patterns could be used as inspiration to explicitly define patterns similar to the method used to describe irregular grid in Figure 28.

### *3.3.6 Diagonal*

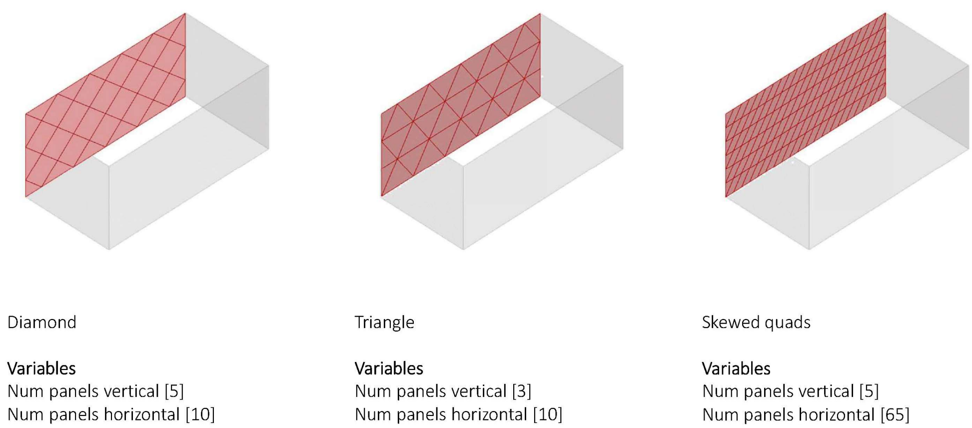



**Figure 36: Example diagonal patterns and variables**

Figure 36 illustrates three different kinds of diagonal patterns: diamond, triangle, and skewed quads. While distinct, these patterns are related in the combination of diagonal lines in one or more directions and/or horizontal lines. They can be seen in Douglas L. McCrary Training Center by TOWNES + architect (Figure 37a), Bankkantoor ASLK/BNP Parisbas by Marcel Lambrichs (Figure 37b), and The Broad Museum by Diller Scofidio + Renfro (Figure 37c) respectively. Each of these patterns is again controlled by two parameters – number of panels vertically and number of panels horizontally. It is worth noting that the diamond pattern in Douglas L. McCrary Training Center is actually reveals in the surface, not joints between panels. In addition, while the Bankkantoor ASLK/BNP Parisbas panels are mostly defined by a triangular pattern across the façade surface, there are obviously some adjustments that are made for connection details. These distinctions will be clarified further through example precast maps in Chapter 5.

a b c

**Figure 37: Example diagonal patterns in precedent buildings ***

### 3.4 Regions

In many of our precedent buildings with architectural precast concrete façades, there is more than one pattern present on a surface. In this research, the extent of each of these different patterns is called a "region." Each region of a surface can have a different pattern applied to it. Examples of this concept are shown in Figures 38 (defined regions) and 39 (patterns applied to different regions). Cavieres and Gentry (2015) used the concept of regions within surfaces to "support the descriptions of various levels of detail… [and] model views necessary for particular data queries and exchanges." This concept may also

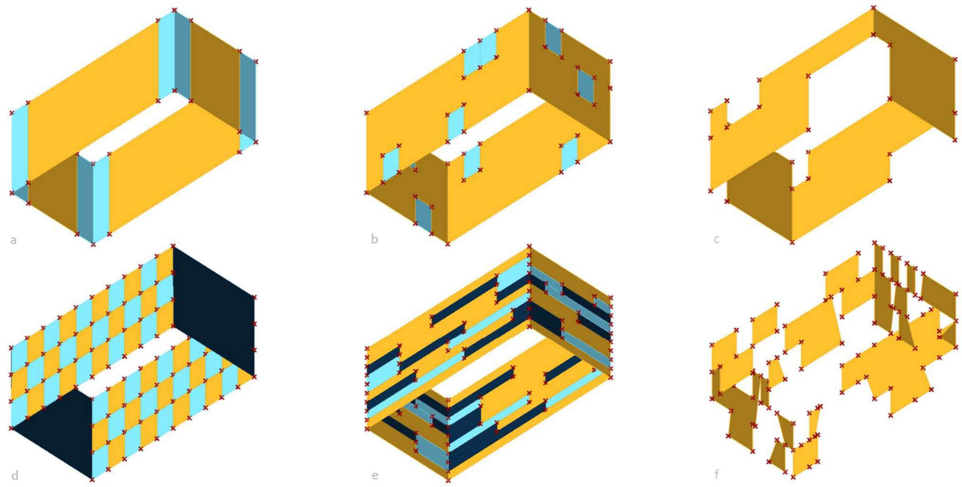



**Figure 38: Example regions applied to surfaces**

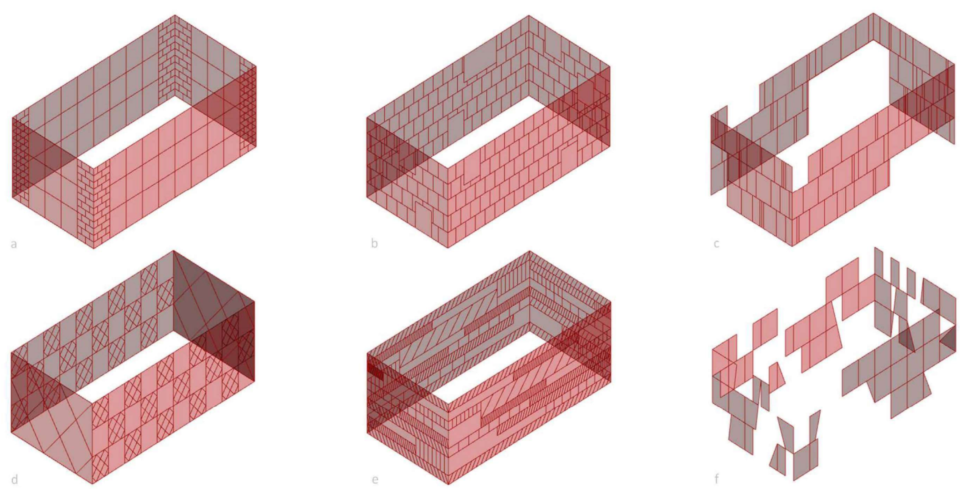



**Figure 39: Example patterns applied to regions**

serve as a design tool, allowing various compositions of panel types, patterns, or materials to be arranged on building façades. This can be seen in each of the example precedent buildings; the expression of the vertical circulation element in Armstrong Rubber Company Headquarters (Figure 40a), the increasing number of vertical members per bay as the building rises in Dumbo Townhouses by Alloy (Figure 40b), and the appearance of diverse textures in the wings of the James F. Battin United States Courthouse by NBBJ (Figure 40c).

a b c

**Figure 39: Example regions in precedent buildings ***

### 3.5 Limitations of design documents

There is a distinction to be made between design intent and design intentions. The term “design intent” refers to the set of building description documents that are handed over from the designers to those who will construct the building. These documents may take the form of drawings, models, specifications, or other narratives. Chapter 3 has presented the case that scaffold models and surface patterns can similarly represent how the building behaves based on certain functional qualities. It is further suggested that scaffold models and surface patterns can serve as an intermediary building diagram, translating crucial data from design intent model to for-construction model. Moreover, as parametric representations, these depictions are able to adjust to design variations. Design intentions may go beyond these geometrical descriptions, encapsulating all aesthetic, formal, and spatial organizational goals for a project. Bafna (2008) describes the difference as an “imaginative and notational use of architectural drawings.” Such concepts are notoriously difficult to represent in design intent documents. With regards to architectural precast concrete façades, design intentions may include concepts for light, shadow, and texture, just to name a few possible alternative objectives. If not explicitly represented in design intent documents, designers can currently only assure that fabricators understand such goals during the shop drawing submittal review process. The ability for designers and fabricators to coordinate digital models during the design process offers an opportunity to assure these nebulous design intentions are prioritized alongside issues of fabrication and assembly.

This chapter has discussed design parameters and the creation of digital models from the global perspective based on a variety of precedent precast buildings. While these tools define designs, a wide variety of options for scaffold models and surface patterns and compositions are nevertheless still available. Incorporation of such models enables both exploration and the ability to iteratively verify intent. Furthermore, it has been shown how global scaffold models can provide the basic panel boundaries for the exterior surfaces of the building. Chapter 4 will discuss fabricator parameters and the creation of digital models from the local perspective.

# CHAPTER 4. FABRICATOR EXPERT KNOWLEDGE

For some time, design teams have been organizing their processes so that the transfer of design proposals occurs via digital model and online. Others, especially on the construction and fabrication side of the industry, have not been as quick to accept these newer approaches; learning new software and workflows, and defining and customizing digital models takes a large amount of time. In the end, however, since more Owners are requiring digital modelling and BIM processes and documents as part of their design and construction contracts, each fabricator must (re)model the "final" architectural components. ((Re) is in parentheses because the design team likely has a model but it is often not shared or allowed to be referenced by the construction team. "Final" is in quotes to highlight that fact that the proposed model may not, in fact, be a model of the component that will be built; industry knowledge has not necessarily been incorporated.) The fabricator will spend time to model, and then the design team may not be happy to the results. The cycle will repeat. What if, instead, the design team and the fabricators worked together to develop a shared model that represented both the design intent and the fabrication details? To that end, the main question that this chapter seeks to answer is: How can fabricator expert knowledge effect panels? Furthermore, how can this knowledge be captured by digital models and what panel types do architectural precast concrete façades require?

## 4.1 Frames for panel models

Describing and organizing geometric features of architectural precast concrete panels can be made more explicit through the use of "frames," a concept borrowed from computer science and cognitive science. Frames are structured knowledge system that help to describe one's thinking about particular things through a series of connected predefined slots, fillers, values, and inheritance. [Rich and Knight, 2009] Further described by Minsky (1974):

> "When one encounters a new situation (or makes a substantial change in one's view of the present problem) one selects from memory a structure called a Frame. This is a remembered framework to be adapted to fit reality by changing details as necessary… A frame is a data-structure for representing a stereotyped situation… We can think of a frame as a network of nodes and relations. The 'top levels' of a frame are fixed and represent things that are always true about the supposed situation. The lower levels have many terminals – 'slots' that must be filled by specific instances or data."

An example frame for an opening (window) panel is shown in Figure 41. Each of the frames "slots" represent variable geometry of the model. "Fillers" for the example model illustrated are listed. Additional frames, such as the geometry of the opening itself, can be linked to respective slots in the top-level frame. These additional frames inherit the geometrical data from upstream. Even more slots can be added and more frames can be associated to increase complexity of the panel form. Such panels will be described later.

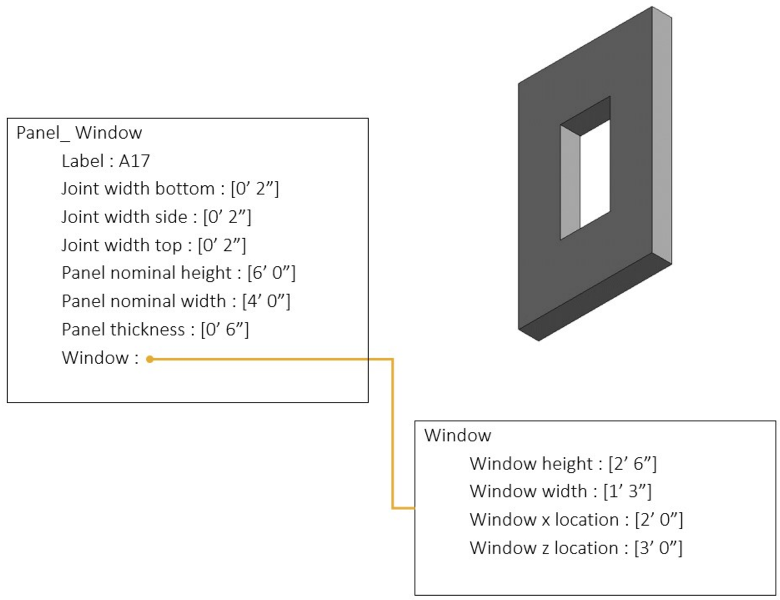



**Figure 41: Example knowledge frame for opening panel**

Each of the slots is associated with an instance parameter in the panel family digital model. Within the modelling software (in this case, *Autodesk Revit*), a basic panel is created with an *Extrusion.* The window opening is produced with a *Void Extrusion.* Each part of the geometry is then given an instance parameter dimension string as shown in Figure 42. When this model is instantiated into a project, each of the filler variables are customizable. This is demonstrated in Figures 43 through 45, which adjust only the window height and window width for the panels as highlighted. Adjusting additional slots creates more panel possibilities from this one panel family. Instantiating and customizing each of the described panel models corresponds to and represents the Fabrication Model exchange following the Precast Detailing stage highlighted in Figure 5.

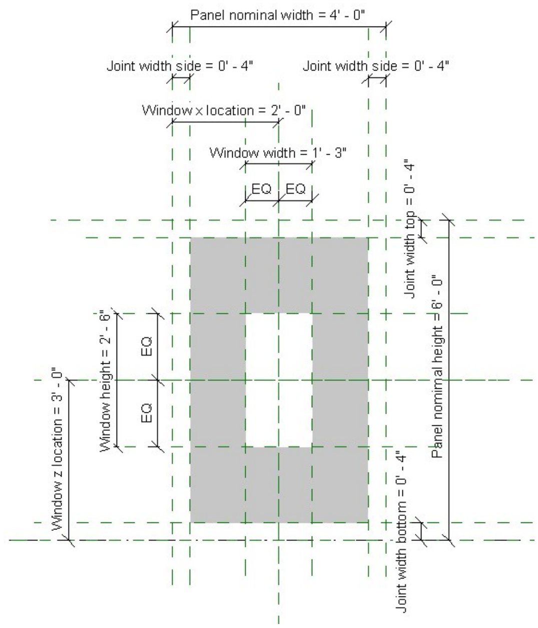



**Figure 42: Example family model for opening panel**

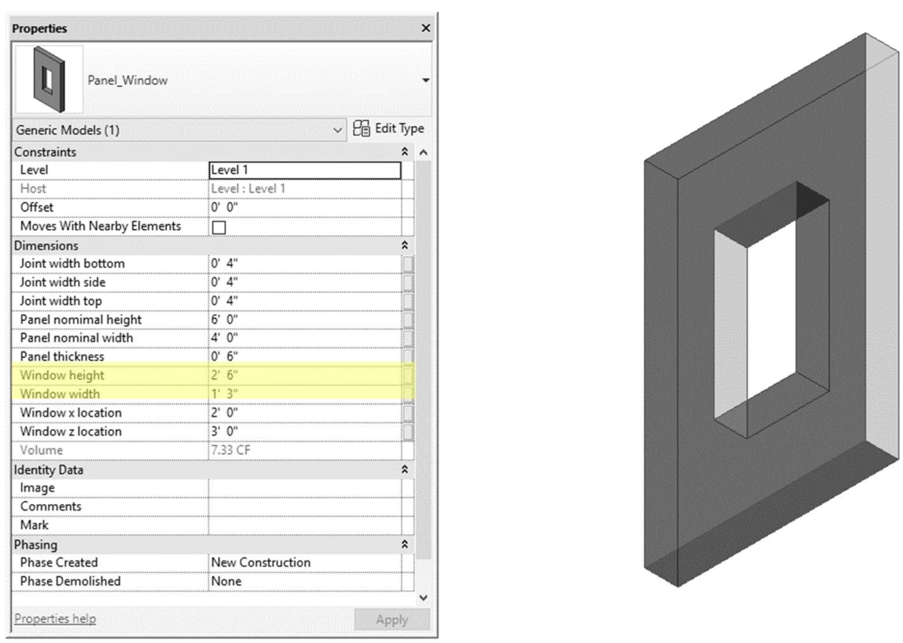



**Figure 43: Customized opening panel – window height [2’ 6”], window width [1’ 3”]**

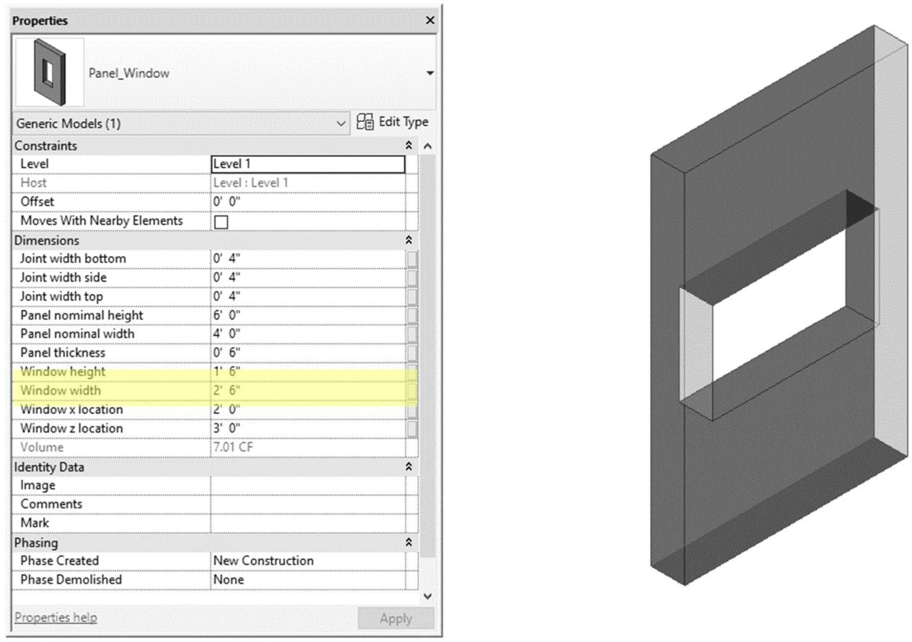



**Figure 44: Customized opening panel – window height [1’ 6”], window width [2’ 6”]**

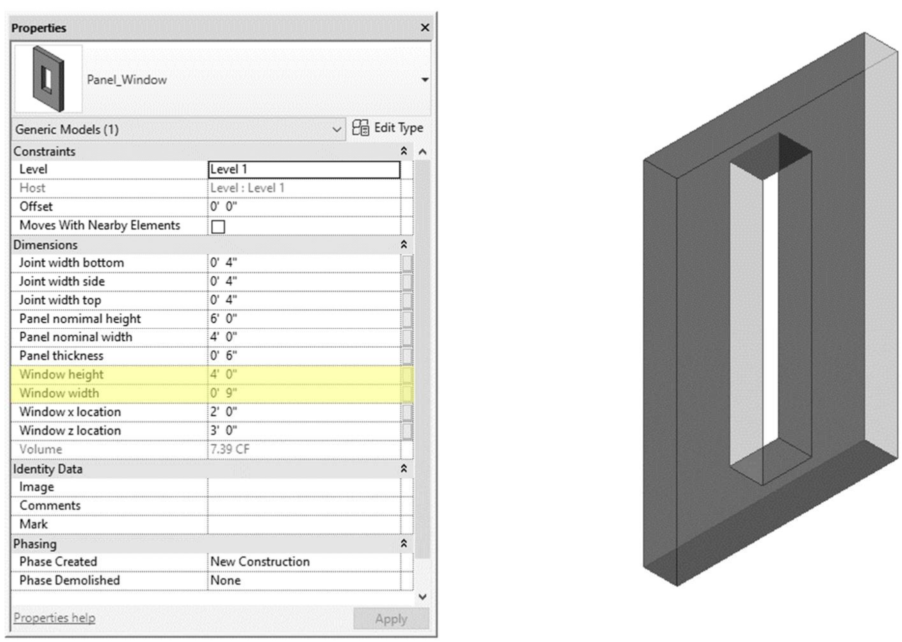



**Figure 45: Customized opening panel – window height [4’ 0”], window width [0’ 9”]**

## 4.2 Codifying expert knowledge

As discussed, one of the results of the work in Collins (2016), was the ability of the precast fabricator to produce shop tickets for a project directly from a digital model of architectural precast concrete panels. Each shop ticket shows one piece of architectural precast concrete, detailing and dimensioning every aspect of each piece that the fabrication team will need to produce it – the shape, details, rebar, locations and types of various embeds and lift points, and any other requirements. An example shop ticket is shown in Figure 46. Certain panel features, which a design intent model may not include – such as holes, notches, reliefs, and reveals between panels, among others – are highlighted and annotated. A larger sample of annotated shop tickets for the Shands project is included in Appendix D. This sample is not comprehensive of all panels on the building, but does demonstrate the variety of panel features required. Each of the features has been translated to panel family models in order to define methods for controlling the geometry. These models are discussed in the next section. Future work could include other features shown on the shop tickets; embeds, rebar, lifting hooks, and more. It is also worth noting that – in addition to standard orthographic representations – some of the shop tickets include an axonometric drawing of the panel; another benefit afforded by the creation of digital models. This would be especially useful when describing unconventional or highly complex geometry difficult to represent or interpret.

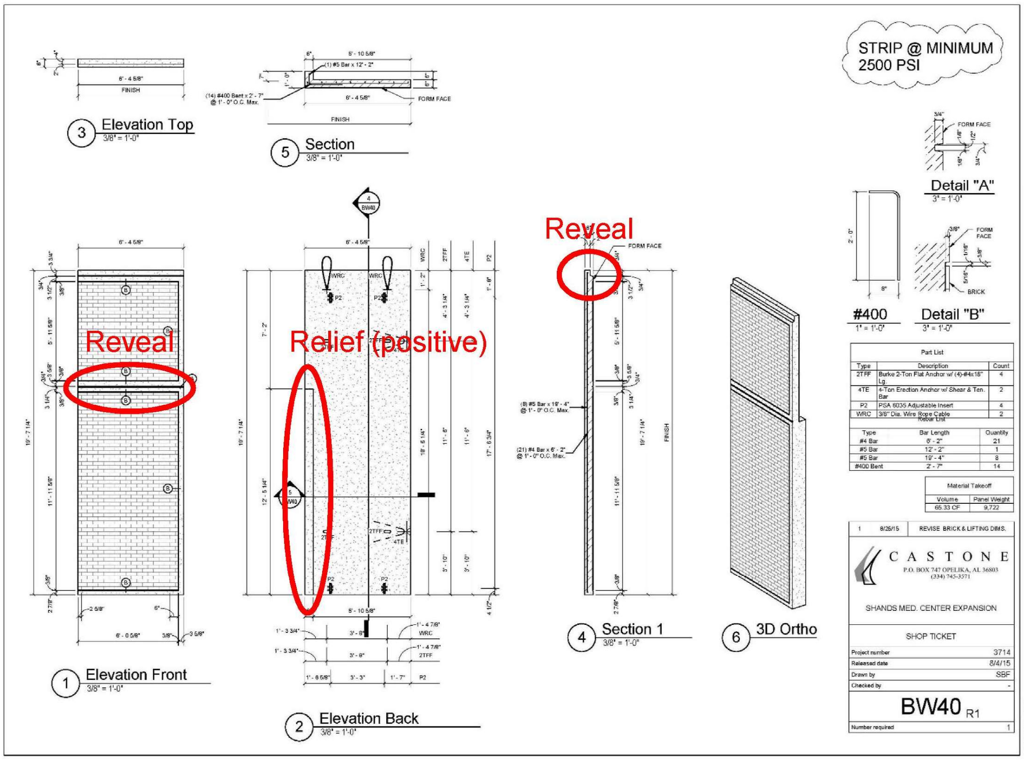



**Figure 46: Example annotated Shands shop ticket**

## 4.3 Panel types and examples

Along with those found in sample shop tickets, observations of panels in our list of precedent buildings in Table 1 express thirteen major types of panel features. Models for each of these as well as example buildings employing these features will be discussed. Modelling techniques for each of these panel types are further described in Appendix E:

1. Flat
2. Non-rectangular
3. Opening (window)

4. Facet (negative and positive)
5. Reveal
6. Notch
7. Taper
8. Rib
9. Hole (circular)
10. Relief patterns and areas (negative and positive)
11. Perforated pattern
12. Corner
13. Gesture

### *4.3.1 Flat (panel)*

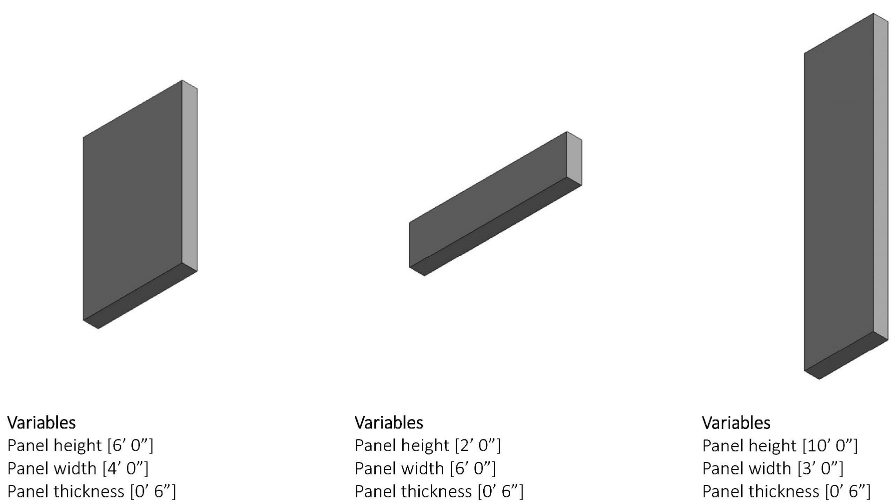
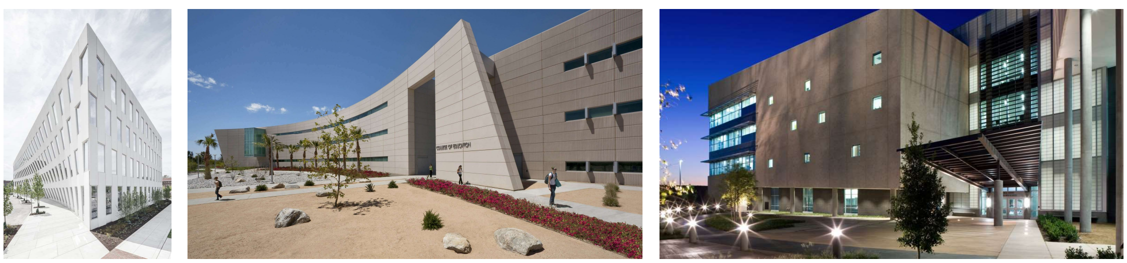



**Figure 47: Example flat panels and variables**

The flat panel is a generic condition to which other features can be added. Shown below are flat panels between windows, with punched windows, as a foil to an expressive shape, and to highlight a composition of windows and reveals. Among many others, flat panels can be seen in 1200 Intrepid by Bjarke Ingels Group (Figure 48a),  California StateUniversity San Bernardino College of Education by LPA (Figure 48b), and Dubaski Career High School by Corgan (Figure 48c). Frank Lloyd Wright also used flat panels in his textile blocks houses to foreground the expressive qualities of other panels with relief patterns and openings. Three parameters control the geometry of (rectangular) flat panels: height, width, and thickness.



a b c

**Figure 48: Example flat panels in precedent buildings ***

### *4.3.2 Non-rectangular*

Examples show non-rectangular shapes applied to a grid (Bank Lambert by Gordon Bunshaft (SOM), Figure 50a), non-rectangular panels created by being cut off by edge of surface shape (Kauffman Center for the Performing Arts by Safdie Architects and BNIM, Figure 50b), and non-rectangular panels created by non-rectangular surface pattern (Bankkantoor ASLK/BNP Parisbas by Marcel Lambrichs, Figure 50c). Each of these examples demonstrates a different way that the panel boundary would be defined. The shape of Bank Lambert panels is defined by a panel profile; a non-rectangular shape manually drawn.

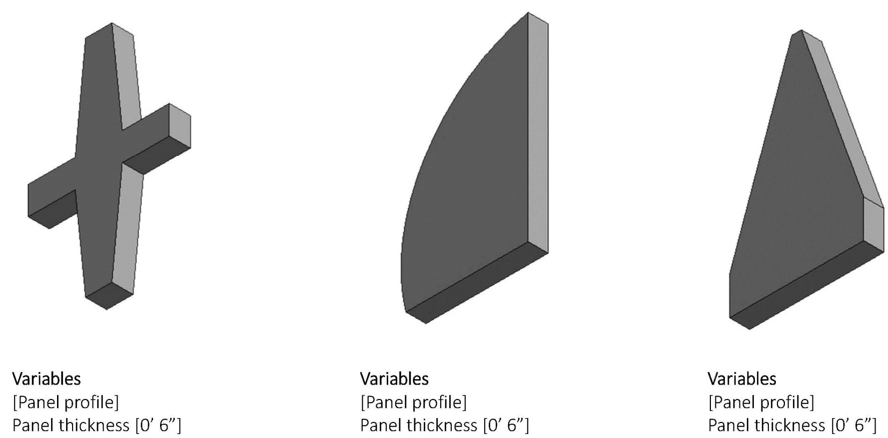



**Figure 49: Example non-rectangular panels and variables**


a b c

**Figure 50: Example non-rectangular panels in precedent buildings ***

### *4.3.3 Opening (window)*

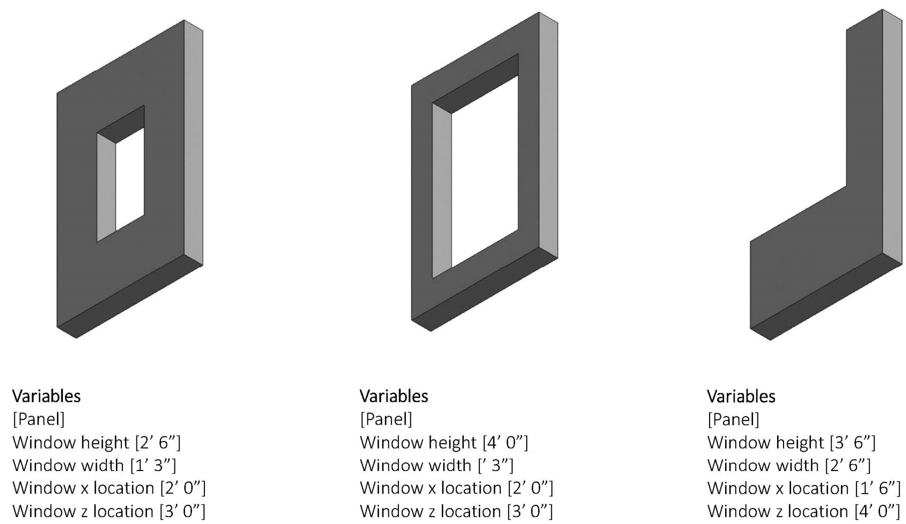
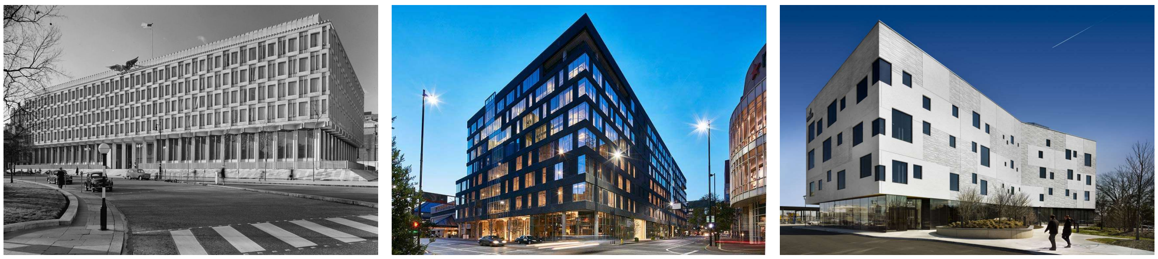



**Figure 51: Example opening panels and variables**

For the example panels with openings shown in Figure 51, four parameters control the opening: window height, window width, window X location, and window Z location. This model defines a size and insertion point for the opening. There are numerous other ways to define the opening. For example, the opening could be sized and located by providing a dimension from each of the edges of the panel. If the opening is always centered on the panel, just two dimensions would be required; a top and bottom dimension and a side dimension. The opening could also be located in relation to the center of the panel instead of from the sides. Simple openings can be seen in U.S. Embassy London by Eero Saarinen (Figure 52a), 84.51° Centre by Gensler (Figure 52b), and 150 Rouse Boulevard by Digsau (Figure 52c). 84.51° Centre is interesting to consider further because the “openings” for the panels often extend all the way to the sides of the panels, creating “L” or “C” shape panels.



a b c

**Figure 52: Example opening panels in precedent buildings ***

### *4.3.4 Opening (non-rectangular)*

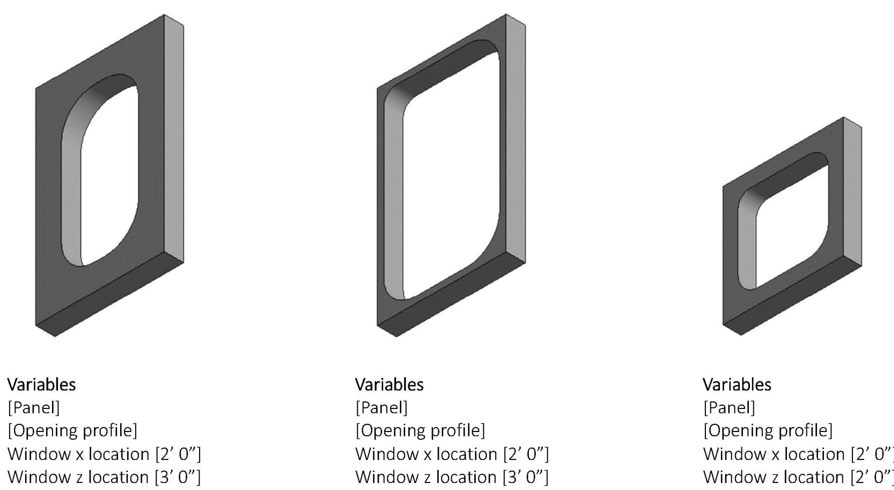



**Figure 53: Example opening (non-rectangular) panels and variables**

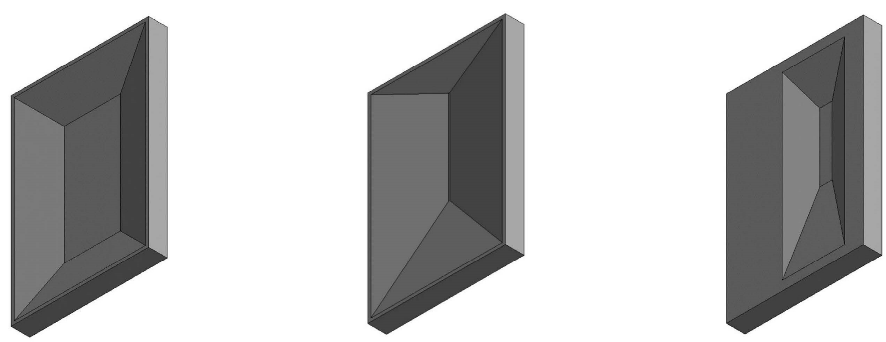
The listed variables for opening non-rectangular suggest that any shape could be used for the opening profile. This is true, though the precedent buildings shown in Figure 54a (Airea by VIDARQ), Figure 54b (CBR building by Constantin Brodzki and Marcel Lambrichs), and Figure 54c (Frost of Museum of Science by Grimshaw and Rodriquez and Quirogo) each have rectangular openings with radiused corners. These openings are created made by varying the fillet radius of a rectangular *Void Extrusion.* CBR building does have some curvature to the sides of the openings which would require some additional modelling. Further examples, such as The Broad Museum by Diller Scofidio + Renfro, have even more complex opening geometry. These could be developed using lofted parametric forms which will be discussed later.

a b c

**Figure 54: Example opening (non-rectangular) panels in precedent buildings ***

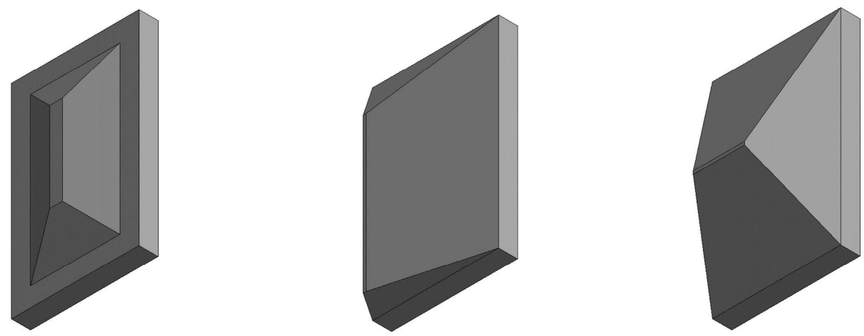
### *4.3.5 Facet (negative and positive)*

There are two types of facets; negative and positive. The negative facet carves away material from the flat panel. The positive facet adds material to the flat panel. Each facet is created by lofting two defined profiles together. In the examples shown, all profiles are rectangles. (Though, again, could be any shape.) The size and location of these rectangles is controlled by nine parameters: back (or front) offset bottom, back (or front) offset left, back (or front) offset right, back (or front) offset top, face offset bottom, face offset left, face offset right, face offset top and facet depth. Positive and negative facets are often used together across a façade or within the same panel to create a play of shade and shadow. Examples are seen in Flaine Hotel by Marcel Breuer and Robert F. Gatje (Figure 57a), University of Houston Health and Biomedical Sciences Building by Shepley Bulfinch (Figure 57b), and Suffolk University 20 Somerset Street by NBBJ (Figure 57c).



| Variables | Variables | Variables |
|---|---|---|
| [Panel] | [Panel] | [Panel] |
| Back offset bottom [1′ 0″] | Back offset bottom [2′ 0″] | Back offset bottom [2′ 0″] |
| Back offset left [1′ 0″] | Back offset left [1′ 8 3/4″] | Back offset left [1′ 0″] |
| Back offset right [1′ 0″] | Back offset right [1′ 8 3/4″] | Back offset right [1′ 0″] |
| Back offset top [1′ 0″] | Back offset top [0′ 8″] | Back offset top [1′ 0″] |
| Face offset bottom [0′ 1″] | Face offset bottom [0′ 1″] | Face offset bottom [0′ 3″] |
| Face offset left [0′ 1″] | Face offset left [0′ 1″] | Face offset left [1′ 6″] |
| Face offset right [0′ 1″] | Face offset right [0′ 1″] | Face offset right [0′ 6″] |
| Face offset top [0′ 1″] | Face offset top [0′ 1″] | Face offset top [0′ 3″] |
| Facet depth [0′ 4″] | Facet depth [0′ 4″] | Facet depth [0′ 4″] |

**Figure 55: Example negative facet panels and variables**



Variables
[Panel]
Front offset bottom [1′ 0″]
Front offset left [1′ 0″]
Front offset right [1′ 0″]
Front offset top [1′ 0″]
Face offset bottom [0′ 6″]
Face offset left [0′ 6″]
Face offset right [0′ 6″]
Face offset top [0′ 6″]
Facet depth [0′ 4″]

Variables
[Panel]
Front offset bottom [0′ 3″]
Front offset left [0′ 3″]
Front offset right [3′ 0″]
Front offset top [1′ 0″]
Face offset bottom [0′ 0″]
Face offset left [0′ 0″]
Face offset right [0′ 0″]
Face offset top [0′ 0″]
Facet depth [0′ 4″]

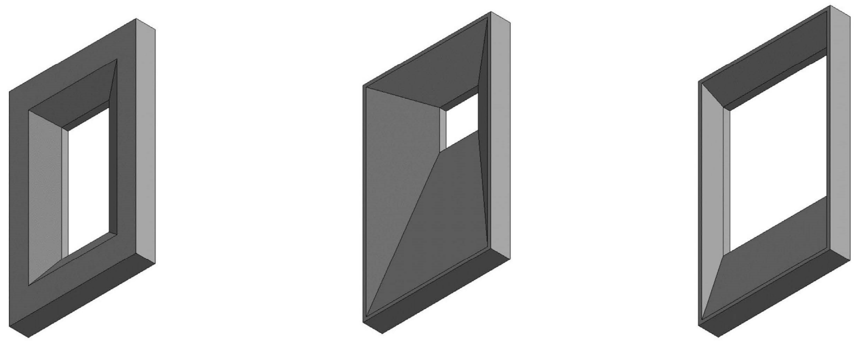
Variables
[Panel]
Front offset bottom [2′ 0″]
Front offset left [1′ 0″]
Front offset right [1′ 0″]
Front offset top [3′ 3″]
Face offset bottom [0′ 0″]
Face offset left [0′ 0″]
Face offset right [0′ 0″]
Face offset top [0′ 0″]
Facet depth [1′ 6″]

**Figure 56: Example positive facet panels and variables**

a b c

**Figure 57: Example facet panels in precedent buildings ***

### 4.3.6 Facet + opening



Variables
[Panel]
Face offset bottom [0’ 8”]
Face offset left [0’ 6”]
Face offset right [0’ 6”]
Face offset top [0’ 8”]
Facet depth [0’ 4”]
Window height [3’ 0”]
Window width [1’ 3”]
Window x location [2’ 0”]
Window z location [3’ 0”]

Variables
[Panel]
Face offset bottom [0’ 1”]
Face offset left [0’ 1”]
Face offset right [0’ 1”]
Face offset top [0’ 1”]
Facet depth [0’ 4”]
Window height [1’ 0”]
Window width [1’ 0”]
Window x location [2’ 6”]
Window z location [4’ 0”]

Variables
[Panel]
Face offset bottom [0’ 1”]
Face offset left [0’ 1”]
Face offset right [0’ 1”]
Face offset top [0’ 1”]
Facet depth [0’ 4”]
Window height [3’ 3”]
Window width [2’ 9”]
Window x location [2’ 0”]
Window z location [3’ 6”]

**Figure 58: Example facet + opening panels and variables**

Made famous by Marcel Breuer (seen in Armstrong Rubber Company Headquarters, Department of Health, Education and Welfare Headquarters (Hubert H. Humphrey Federal Building), Department of Housing and Urban Development Headquarters (Figure 59a), Flaine Hotel, IBM Administrative, Laboratory, and Manufacturing Facility, IBM Research Center, Sarget-Ambrine Headquarters and Pharmaceutical Laboritories, SUNY Buffalo Faculty of Engineering and Applied Science Building Complex, Torin Corporation, Torin Corporation Administration Building, University of Massachusetts Murray Lincoln Campus Center and Yale University Becton Engineering and Applied Science Center to name a few), opening + facet panels have become widely used. Opening + facet panels are also featured in Philadelphia Police Department Headquarters (Roundhouse) by Geddes, Brecher, Qualls and Cunningham (Figure 59b), and University of Chicago Campus North Residential Commons by Studio Gang (Figure 59c) among many other buildings.

Opening + facet panels continue the play of shade and shadow described in facet panels with an additional element of a window opening. There are endless combinations of panels features; the popularity of opening + facet panels in precedent buildings signified this combination should be emphasized in this work.

a b c

**Figure 59: Example facet + opening panels in precedent buildings ***

*4.3.7 Reveal*

Reveals are often associated with edges of window openings or to express structural organization; they create a shadow line and break up the scale of large panels. There are three main parameters that control the geometry of reveal: depth, width, and location. The models shown in Figure 60 each assume rectangular reveal profiles and that they are continuous across a panel. This may not necessarily be the case. (Note that fabricator details would at least slope the bottom of the reveal to allow water to drip.) In addition, current models allow for two types of reveals, horizontal or vertical. This needs to be specified when modelling. In the current framework, non-orthogonal reveals would operate as relief patterns, described in the next section. Among many other buildings, reveals can be seen in Clark and Grand Hotels by HOK (Figure 61a), and Cobank Center by Davis Partnership (Figure 61b).

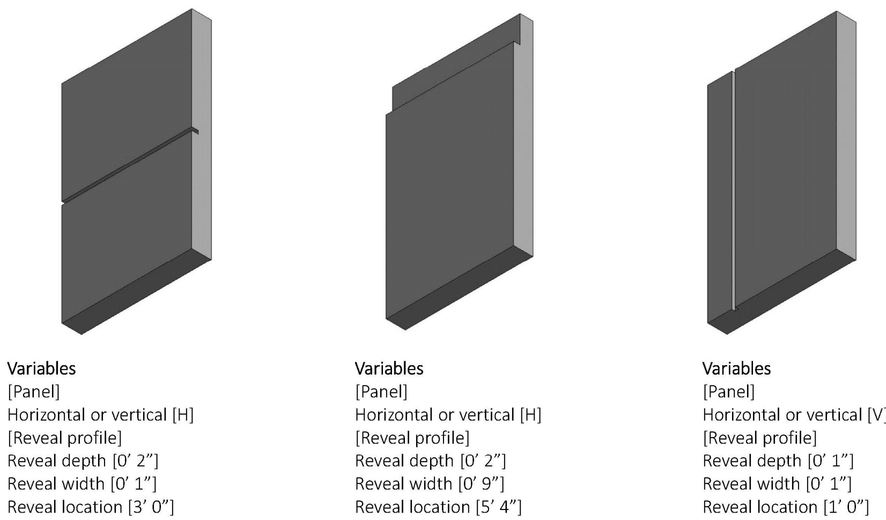



**Figure 60: Example reveal panels and variables**

a b

**Figure 61: Example reveal panels in precedent buildings ***

### *4.3.8 Notch*

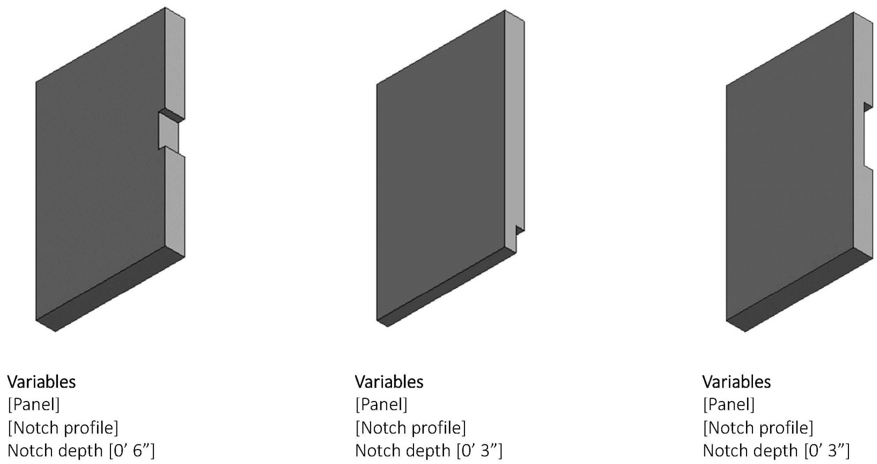



**Figure 62: Example notch panels and variables**

The notch feature is similar to both reveal and relief area (discussed below) in geometrical construction. The distinction is its location and function. While reveals and reliefs are associated with the front face of panels and are generally aesthetic, notches can be on panel sides or back faces as required for coordination. Panels on The Ohio State University South Campus Chiller Plant by Ross Barney Architects (Figure 63) have notches to receive brackets for fins that protrude from the façade. These colored and textured glass fins create fascinating effects on the precast façade. Notches may also be required to allow for panel geometry to "jog" around building structure or other fixtures.

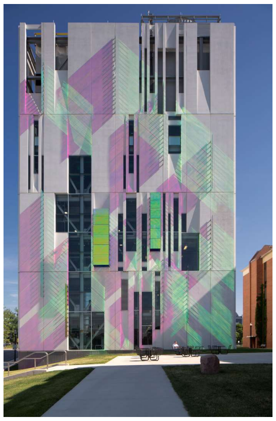


**Figure 63: Example notch panel in precedent building ***

*4.3.9 Taper*

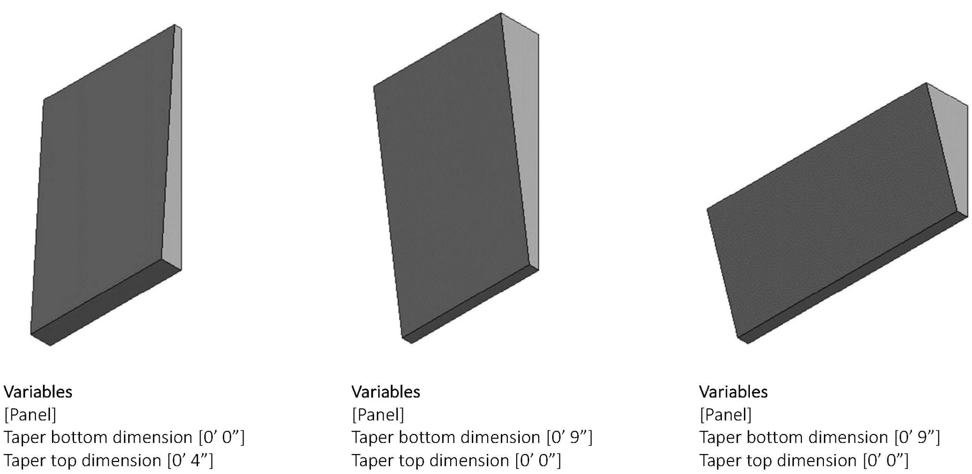
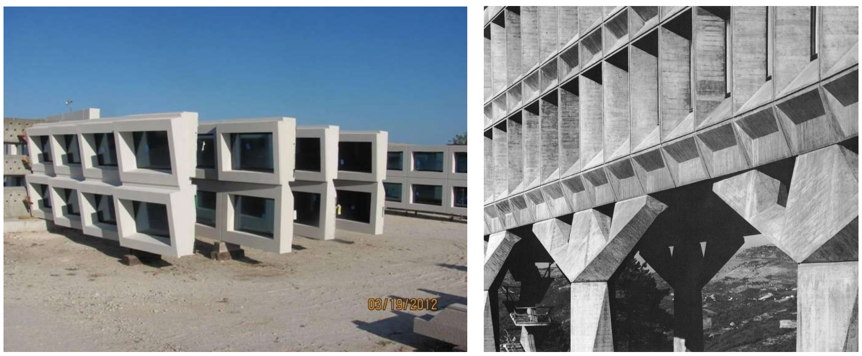



**Figure 64: Example taper panels and variables**

Panels do not necessarily have parallel front and back faces. These are categorized as facet panels. Examples can be seen in Florida International University Academic Health

Center by Perkins + Will (Figure 65a) and IBM Research Center by Marcel Breuer and Robert F. Gatje (Figure 65b). In both of these examples, tapering reveals the thickness of the panels. Variables adjust the top or bottom of the front face of the panel. Current models allow tapering to occur in one direction; from top to bottom or side to side. Future work could allow panel tapering in multiple directions.



a b

**Figure 65: Example tapered panels in precedent buildings ***

### *4.3.10 Rib*

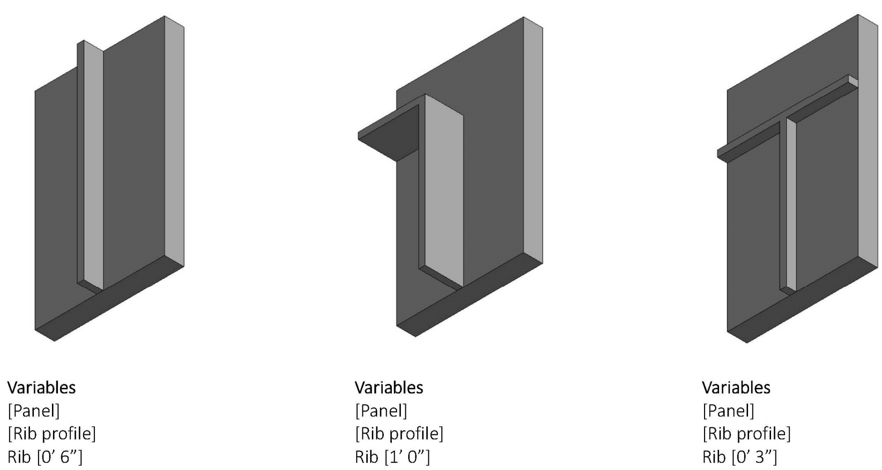



**Figure 66: Example rib panels and variables**

The rib feature was previously discussed in Section 2.2 in the description of designer and fabricator collaboration for IBM Administrative, Laboratory, and Manufacturing Facility (Figure 67a) and IBM Research Center (Figure 67b), both projects by Marcel Breuer and Robert F. Gatje. A profile is defined for the rib and this is extruded from the panel face. Like other "profile" features, any shape can be defined and used as a rib. In addition to a rib depth variable, the example panels shown in Figure 66 each have a rib width parameter. This may or may not be the case for all ribs. (Ribs could taper in profile, for example.)

a b

**Figure 67: Example rib panels in precedent buildings ***

*4.3.11 Hole (circular)*

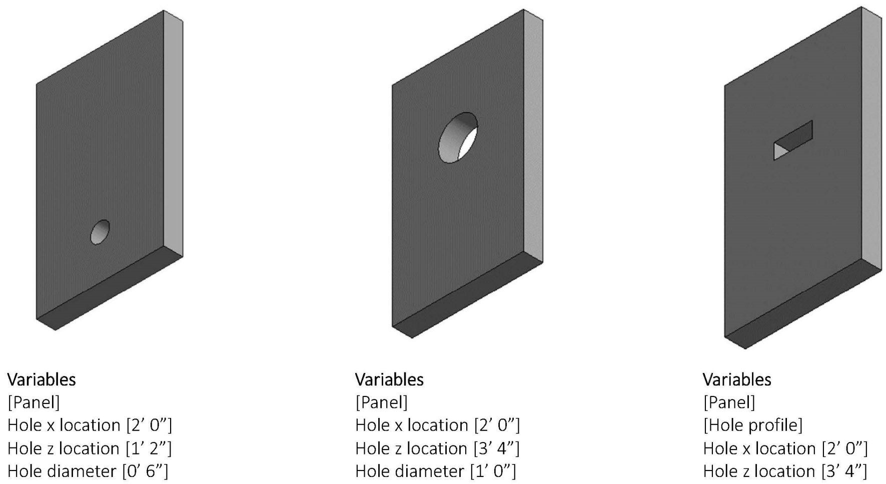



**Figure 68: Example hole panels and variables**

Holes are distinguished from openings in that they are formed to allow mechanical, plumbing, or other systems to pass through the wall. Similar to the opening panel, there is the possibility of inserting other shapes besides a circle – shown in the examples in Figure 66 – as the profile of the hole. They are defined by a hole profile and location. The holes in the façade of CEDETEC by LANDA Arquitectos (Figure 69a) appear to be aesthetic but are used an as example here to show the intent of this panel family. Holes in the Hansberry College Prep by Wheeler Kearns Architects (Figure 69b) façade are more typical. These appear to be rectangular vents.

a b

**Figure 69: Example hole panels in precedent buildings ***

*4.3.12 Relief patterns and areas (negative and positive)*

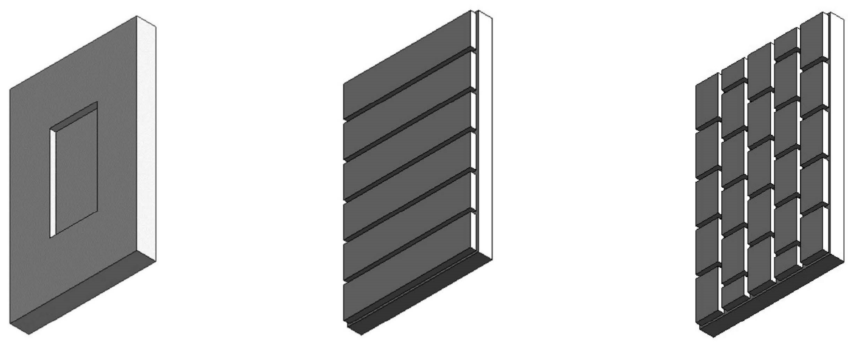
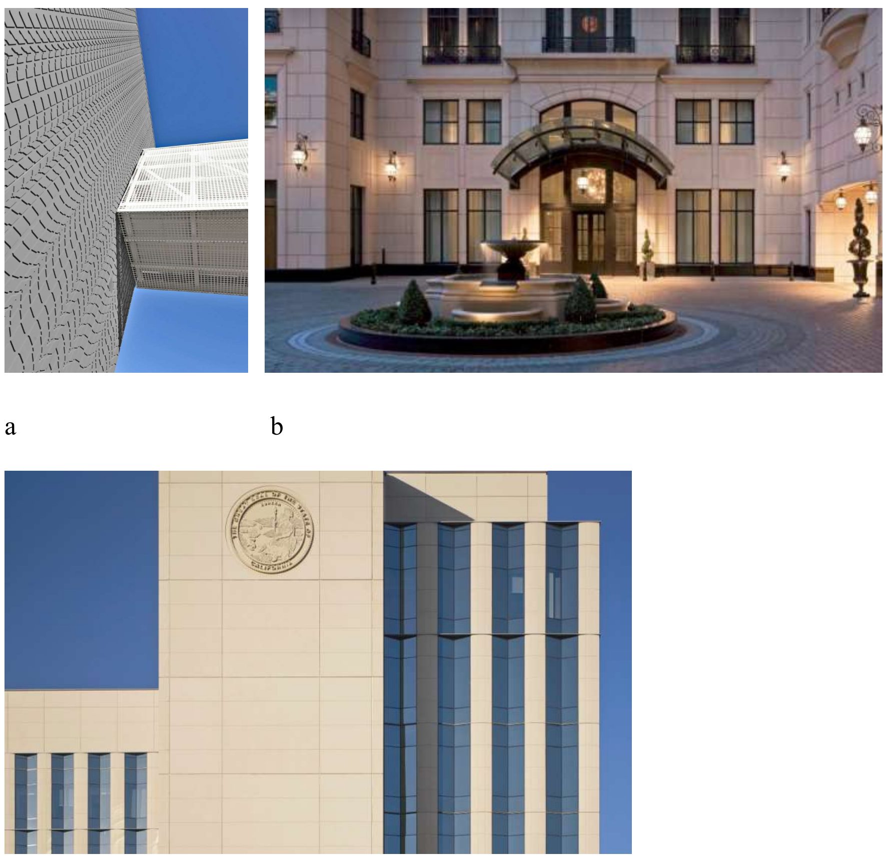



**Figure 70: Example relief pattern and area panels and variables**

In some ways, a relief area is a bit like an opening, specifying height, width, and location. However, there is an additional parameter of depth into or out from the panel surface. Some buildings have used this concept for signage; the relief area being letters such as in City of Miami College of Policing, Miami-Dade School of Law Studies, Homeland Security, and Forensic Sciences by AECOM. Relief patterns can be seen in Dollar General Distribution Center by Leo A Daly (Figure 71a), Waldorf Astoria Chicago by Lucien Lagrange Studio (Figure 71b), and Judicial Council of California, Superior Court of California, County of Santa Clara, Family Justice Center Courthouse by ZFG Architects (Figure 71c). Relief patterns are similar to surface patterns. This is will be discussed further in Chapter 5 regarding patterns across panels and panelization.



a b

c

**Figure 71: Example relief patterns and areas in precedent buildings ***

*4.3.13 Relief + opening*

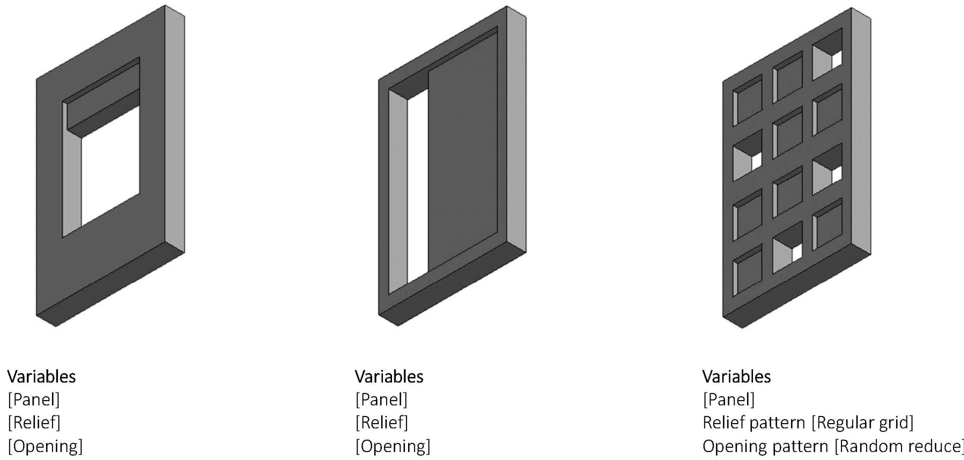


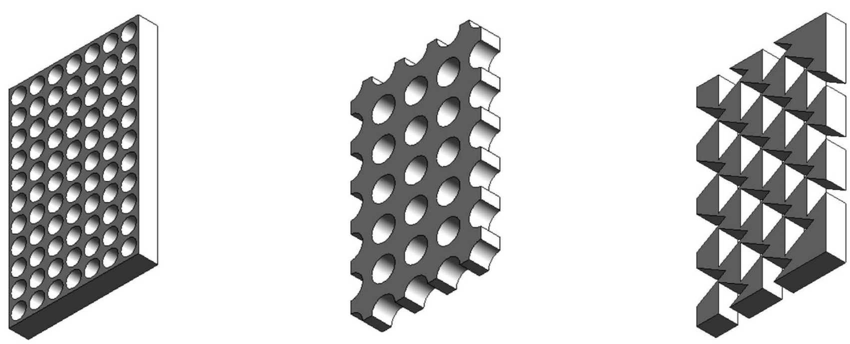

**Figure 72: Example relief + opening panels and variables**

Relief + opening, another common combination of features, add interest to panels. An added level of coordination is required for these panels as the patterns of reliefs and openings are often associated. In the first two examples in Figure 72, the relief extends the area of the opening across a larger portion of the panels. In the third example, openings are formed by increasing the depth of elements of the relief pattern. Like facet + opening, geometry and parameters for relief + opening can be linked so that one adjusts when the other does. Relief + opening panels can be found in Millard Residence (La Miniatura) by Frank Lloyd Wright (Figure 73a), Osage Prairie YMCA Natatorium Addition by SFS Architecture (Figure 73b), and Roseville City Hall Annex by LPAS Architect (Figure 73c).

a b c

**Figure 73: Example relief + opening panels in precedent buildings ***

*4.3.14 Perforated pattern*



Variables
[Panel]
Perforation pattern [Regular grid]
Num panels vertical [10]
Num panels horizontal [6]
Perforation profile [Circle]
Perforation radius [.20]

Variables
[Panel]
Perforation pattern [Regular grid]
Num panels vertical [6]
Num panels horizontal [4]
Perforation profile [Circle]
Perforation radius [.30]

Variables
[Panel]
Perforation pattern [Diamond]
Num panels vertical [8]
Num panels horizontal [5]
Perforation profile [Triangle]
Perforation radius [.50]

**Figure 74: Example perforated pattern panels and variables**

Similar panel embelishing is exhibited through perforated patterns. Again found in many contemporary examples, a pattern is distributed across entire panels to create panel openings. (This is a key concept – patterns can define panels and patterns can be applied to panels.) Perforated patterns can be seen in Simons Galeries d'Anjou by Lemaymichaud (Figure 75a) and Hotel Residencial Nakâra by Jacques Ferrier Architecture (Figure 75b). This topic will be discussed further in Chapter 5 regarding patterns across panels and panelization. In addition to the typical variables, these panels also require perforation profile and size.


a b

**Figure 75: Example perforated patterns in precedent buildings ***

*4.3.15 Corner*

Creating a corner panel involves either joining two or more panels together or using a *Void Extrusion* to create mitred corned panel. Corner panel may continue around in plan (exemplified in Figure 77a, Atlanta Central Public Library by Marcel Breuer and Hamilton P. Smith and Stevens and Wilkinson) or in section, from wall to underside of soffit. Figure 77b, Burntwood School by Allford Hall Monaghan Morris, has corner panels that also include facets and openings. Minnesota Senate Building by BWBR (Figure 77c) has corner panels where the short leg of the "L" shape panel protrudes from the façade to create vertical fins.

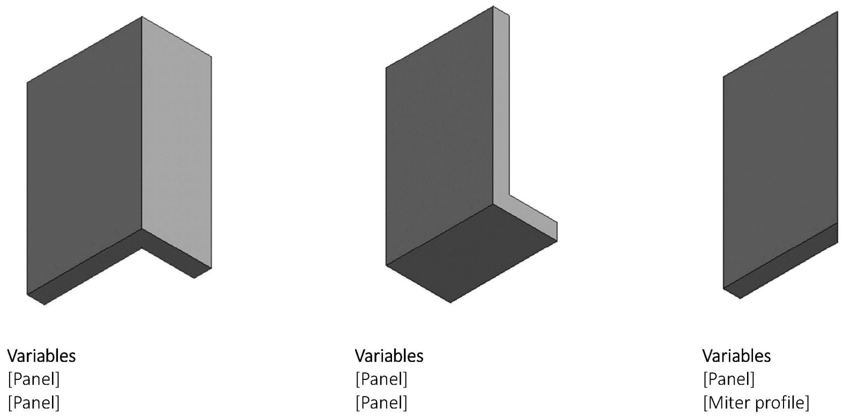


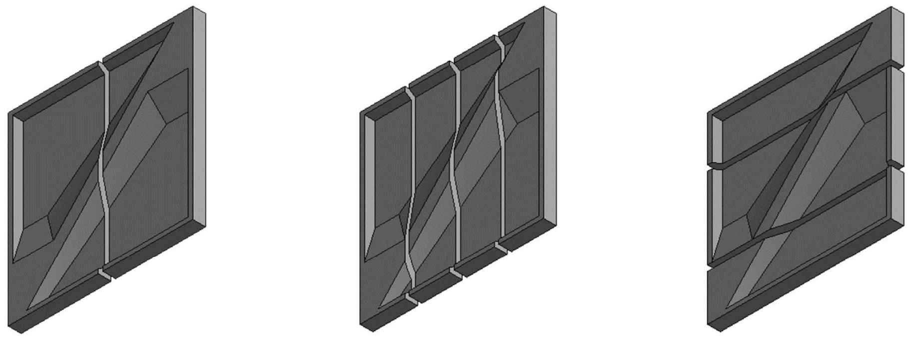

**Figure 76: Example corner panels and variables**

a b

c

**Figure 77: Example corner panels in precedent buildings ***

*4.3.16 Gesture*



| | | |
|---|---|---|
| Variables | Variables | Variables |
| [Panel] | [Panel] | [Panel] |
| [Gesture] | [Gesture] | [Gesture] |
| Panelization pattern [Regular grid] | Panelization pattern [Regular grid] | Panelization pattern [Irregular grid] |
| Num panels vertical [1] | Num panels vertical [1] | Num panels vertical [3] |
| Num panels horizontal [2] | Num panels horizontal [4] | Num panels horizontal [1] |

**Figure 78: Example gesture panels and variables**

a b

**Figure 79: Example gestures in precedent buildings ***

The gesture panel divulges a concept that will be discussed in Chapter 5 regarding panelization and patterns across panels – that sometimes a formal "gesture" on a panel may cross over two or more panels. This panel type is noted in Armstrong Rubber Company Headquarters by Marcel Breuer and Robert F. Gatje (Figure 79a) and Perot Museum of Nature and Science by Morphosis (Figure 79b), previously discussed in Section 2.4.

### 4.4 Constraints beyond geometry

Research has involved creating digital models in order to have conversations with fabricators regarding model operability. One such conversation is documented in Appendix C. [Fisher, 2018] further provided a list of “the changes and constraints that [precasters] typically have to add to an architect’s panelized precast model,” as follows:

- Precast to precast joints should be minimum three-quarters of an inch
- Precast to structure joints should be minimum two inches (per PCI best practices… anything lower [than one-and-a-half inches] usually means that the panel has to be thinned or blocked out)
- Consider maximum panel width and height on the truck (Sizes are subject to state and federal trucking laws regarding freight that can be trucked without being “oversized.” Indexing and arranging panels on the trailer also a factor.)
- Consider maximum weight (Subject to trucking limits, crane capacity and plant capacity, which can vary from thirty thousand pounds to sixty thousand pounds.)
- Adding a “draft” or a “flare” to reveals
- Adding chamfers to corners and miters (A square reveal or edge sticks in the form, and a thin knife-edge miter is usually too fragile to ship without damage)

Data distilled from the above and similar expert knowledge has been used in increase the functionality of current global and local digital models. Incorporating this functionality will benefit similar future discussions among designers and fabricators; rather than attempting to completely constrain panel models, this work can enable conversations among designers and fabricators. This is because the fabricator is actually considering many the panel features together; balancing fabrication, assembly, and transportation issues (and others), along with design intent. Key to this conversation is the ability to control, or "map," global and local descriptions intentionally and precisely to one another.

As will be discussed further in Chapter 5, one factor in mapping architectural precast concrete façades is that "panelization" cannot be assumed by looking at the building. Panelization is the pattern that defines the bounds of individual pieces of precast. This pattern may be different than the surface pattern; those described in Section 3.3. An example is revealed in Shands Cancer Hospital. The image in Figure 3 shows a regular grid pattern. However, when it came to fabrication, panelization for the wall was made vertical running bond:

> "The height [of the upper most panel] changed because the structure couldn't support the load of two panels side by side that span two floors... we had to stagger the panels on that tower as you go up the tower so that the gravity connections were on different floors. That situation also occurs on the West tower. The other two towers had to be broken up every floor for structural reasons as well. [Farr, 2016]

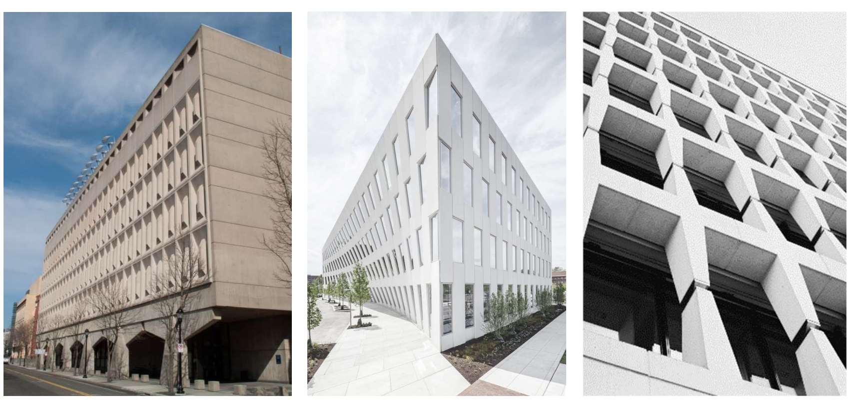
This chapter has discussed fabricator parameters and the creation of digital models from the local perspective based on a variety of precedent precast buildings. While these tools define designs, a wide variety of options for panel models are nevertheless still available. Incorporation of such models enables both exploration and the ability to iteratively verify the feasibility of panel features and, via expert knowledge, combinations of features. Chapter 5 will discuss how global and local descriptions map to one another.

# CHAPTER 5. MAPPING PRECAST

Having defined various scaffolds and panel types for architectural precast concrete façades in parametric digital models, the main question that this chapter seeks to answer is: How do global and local descriptions of architectural precast concrete façade patterns and panels map to one another? The notion of linking these descriptions is underpinned by the widespread belief that "the historical roles of the designer as an author, a sole creator, is being replaced with semi-autonomous, algorithmically driven design workflows deeply embedded in a collective of digital communication infrastructure." [Marble, 2012] In fact, the current disconnect of global and local descriptions extends beyond technical modes of working and depicting projects to conceptual meanings of drawings (or models) and cognition. Mitchell (1990) refers to these two approaches as "graphic primitives and abstract shape types" (such as scaffold models and surface patterns) and "instantiated labeled objects" (such as panel models). It can be further argued that the disconnect between building descriptions has been exaggerated by industry-focused software which align with goals for certain project actors; designer exploration and fabricator specification. To bring this point to light, global descriptions in Chapter 3 were developed in *Grasshopper* and *Rhino* while local descriptions in Chapter 4 were modelled in *Revit*. "Mapping" can elucidate and associate global and local representations, not only of the digital models but also within the minds of designers and fabricators; maps will serve as manifestations of "distributed cognition" for projects. [Hutchins, 2001] While this is true for other building descriptions – digital, technical, sketch, or otherwise – the use of digital models can unleash the capacity of computation to extend projects beyond those that can be traditionally represented while engaging form, materiality, and ways of making. [Shelden, 2002; Shelden, 2014] Two main categories for mapping precast are presented: direct and indirect. Each of these categories has two types that will be discussed. Within direct mapping, data can be pointed both from scaffolds to panels and from panels to scaffolds. Under indirect mapping, the two examples are identified as "panelization" and "patterns across panels." Models of precedent buildings will be used to explain the differences between each of these, conceptually as well as computationally.

## 5.1 Direct

In "direct" mapping, individual panel boundaries – defined by a combination of scaffold models, regions, and surface patterns – allow simple mapping of data from global to local or from local to global descriptions. That is, each individual panel boundary defines a single piece of architectural precast concrete. It should be noted that the term "direct" is used conceptually here, denoting the relationship between panel boundary and panel. Direct exchanges of model data (discussed in Section 1.3.3) uses the term literally, transferring data between actors; this continues to be a goal of this research.

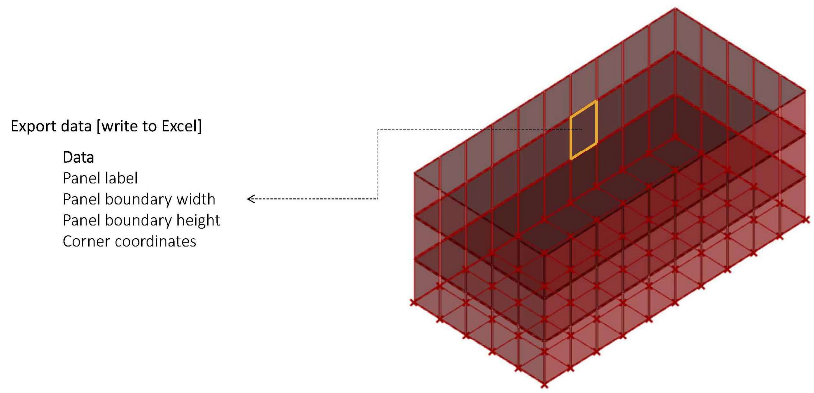


a b c

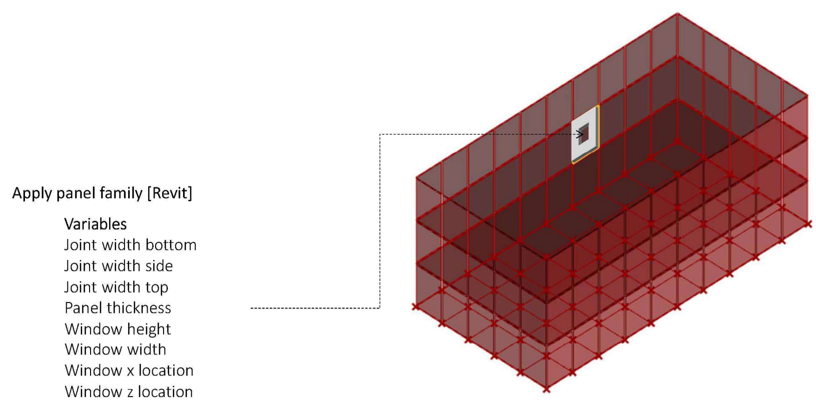
**Figure 80: Direct mapping in precedent buildings ***

### *5.1.1 From scaffolds to panels*

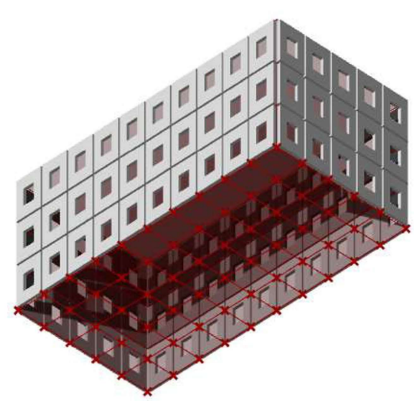
An initial example using the simple scaffold model from Figure 18 and the opening panel model described in Section 4.3.3 is employed to demonstrate the process of linking global and local descriptions of architectural precast concrete panels and façades directly to one another. Shown in Figure 81, data regarding individually defined panels is exported from *Rhino* and *Grasshopper* to *Microsoft Excel* (Figure 81a) and subsequently imported into *Dynamo*. A predefined architectural precast concrete panel family model is then applied via *Revit*, allowing the user to customize the panel details and parameters (Figure 81b). The list of data exported from the scaffold model and the parameters defined within the *Revit* family corresponds to and represents the Fabrication Model exchange following the Precast Detailing stage highlighted in Figure 4. This mapping can occur iteratively across each of the building surfaces (Figure 81c). Each panel can be individually customized; they can all be the same, or some combination of various features can occur. The parametric scaffold controls the location (on the building surface as well as relative to the buildings structural system), nominal width and height of each panel as well as the joint dimension between panels. Detailing of the panels – which, for this example, is window location, width, and height, but could include many more panel features – is controlled at each individual panel.




a




b



c

**Figure 81: Direct mapping from scaffold to panel – export data (a), apply panel family (b), iterate (c)**

5.1.1.1 <u>Example: Suffolk University 20 Somerset Street</u>

Demonstration of direct mapping from scaffold to panel is achieved through modelling Suffolk University 20 Somerset Street by NBBJ (Suffolk), Figure 82. The architects describe the building as “clad in subtly textured precast concrete for its affordability, energy efficiency, durability and its aesthetic fit with other concrete and masonry buildings nearby.” [NBBJ, 2018] The surface pattern for the building is staggered quads. Panels are negative facets.

a b

**Figure 82: Suffolk University 20 Somerset Street from [NBBJ, 2018]**

Suffolk panels require a slight variation to the negative facet panel model described in Section 4.3.5. This modification is illustrated in Figures 83 and 84. The former negative facet panel had four dimensions for the “back face” of the facet; from the bottom, left, right and top. For Suffolk, the “back offset bottom” and “back offset left” are replaced with “facet back height” and “facet back width.” This change allows each of the panel heights and widths to vary while the location of the back face of the facet remains constant relative to the right side and top of the panel. These parameter changes are highlighted in Figure 83 and 84. Possible variations of the new Suffolk panel are shown in Figure 85. Note each of these has the same variables because the size of the panel is determined by the scaffold.

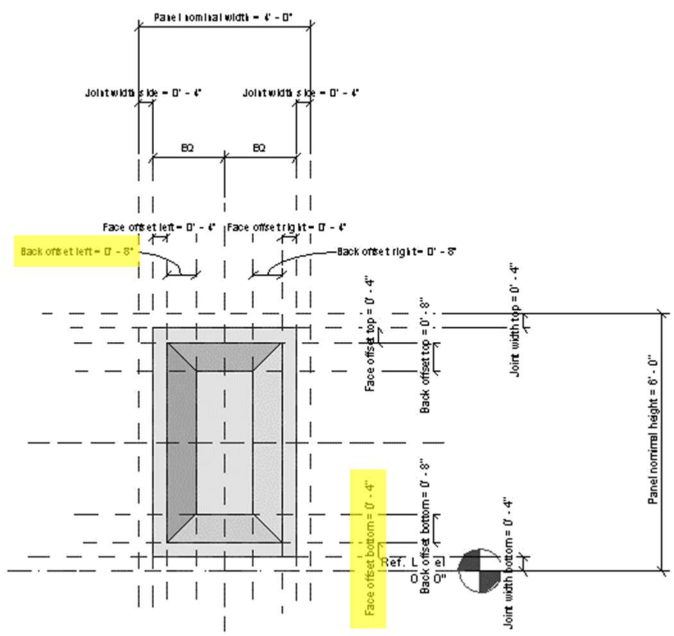



**Figure 83: Facet negative panel front view**

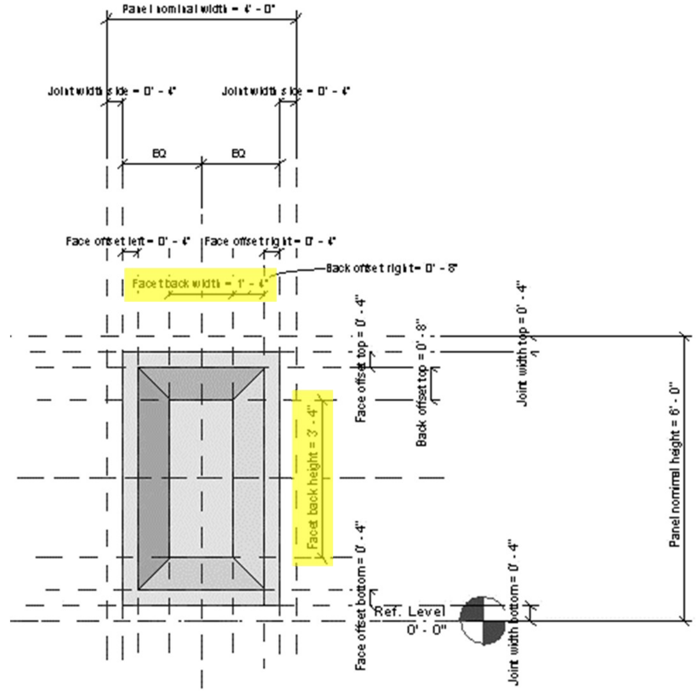



**Figure 84: Suffolk panel front view**

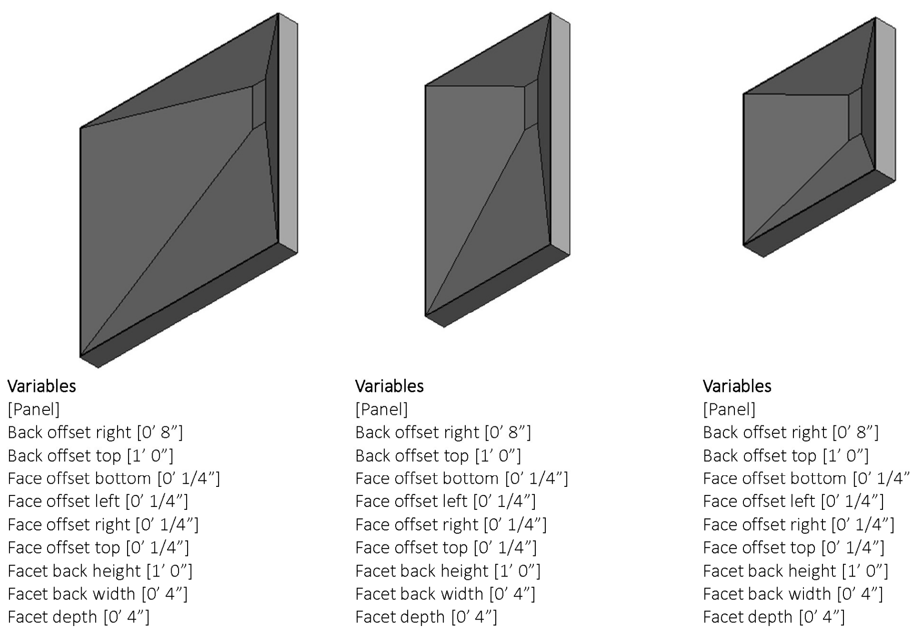



**Figure 85: Example Suffolk panels and variables**

A diagrammatic scaffold for Suffolk is illustrated in Figure 86. The façades of the building are separated into three regions, by level; the first two levels are all glass, floors three through five are the first region of precast (colored yellow in Figure 87a), floors six through nine are the second region of precast (colored light blue in Figure 87a). Each of top two regions in then further separated into "regions within regions," shown in Figure 87b. This allows some vertical strips to be randomly removed. The remaining regions are split into individual panel boundaries. Then, similar to as described in Section 5.1.1, data regarding individually defined panels (Figure 88a) is exported from *Rhino* and *Grasshopper* to *Microsoft Excel* (Figure 88b) and subsequently imported into *Dynamo* whereupon the predefined Suffolk panel family model is then applied via *Revit*, (Figure 88c). This process repeats until all panels are present, represented in Figure 89. It is worth noting again that each of the individual panel model remains customizable with additional features. Such features may include refining joints between panels, interfacing with other material or building structure, or the addition of embeds or lifting hooks. A detailed description of the script for this model is provided in Appendix F.

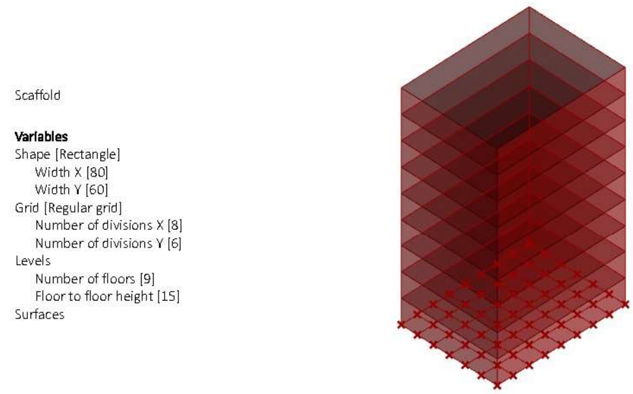
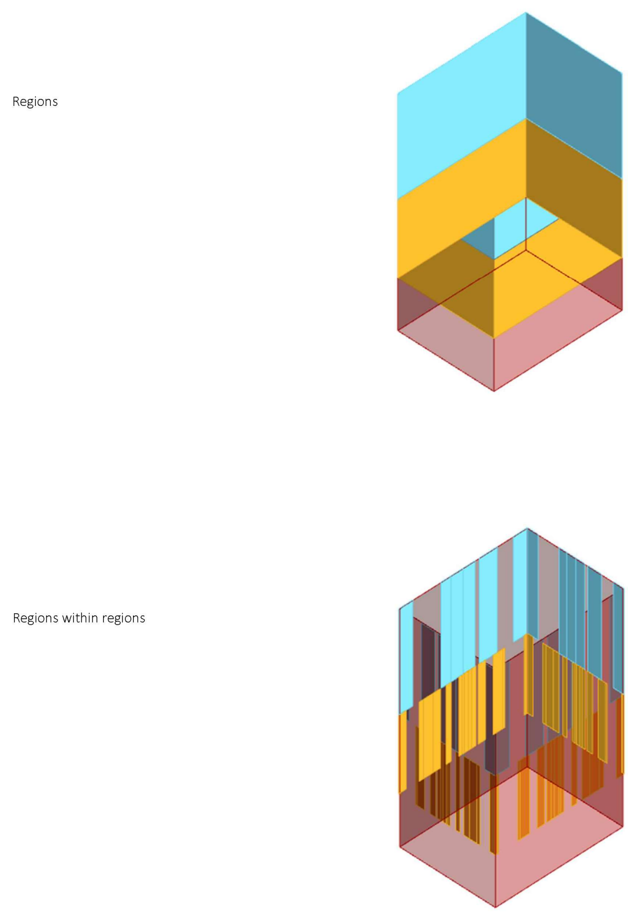



**Figure 86: Suffolk scaffold**




a

b

**Figure 87: Suffolk regions (a) and regions within regions (b)**

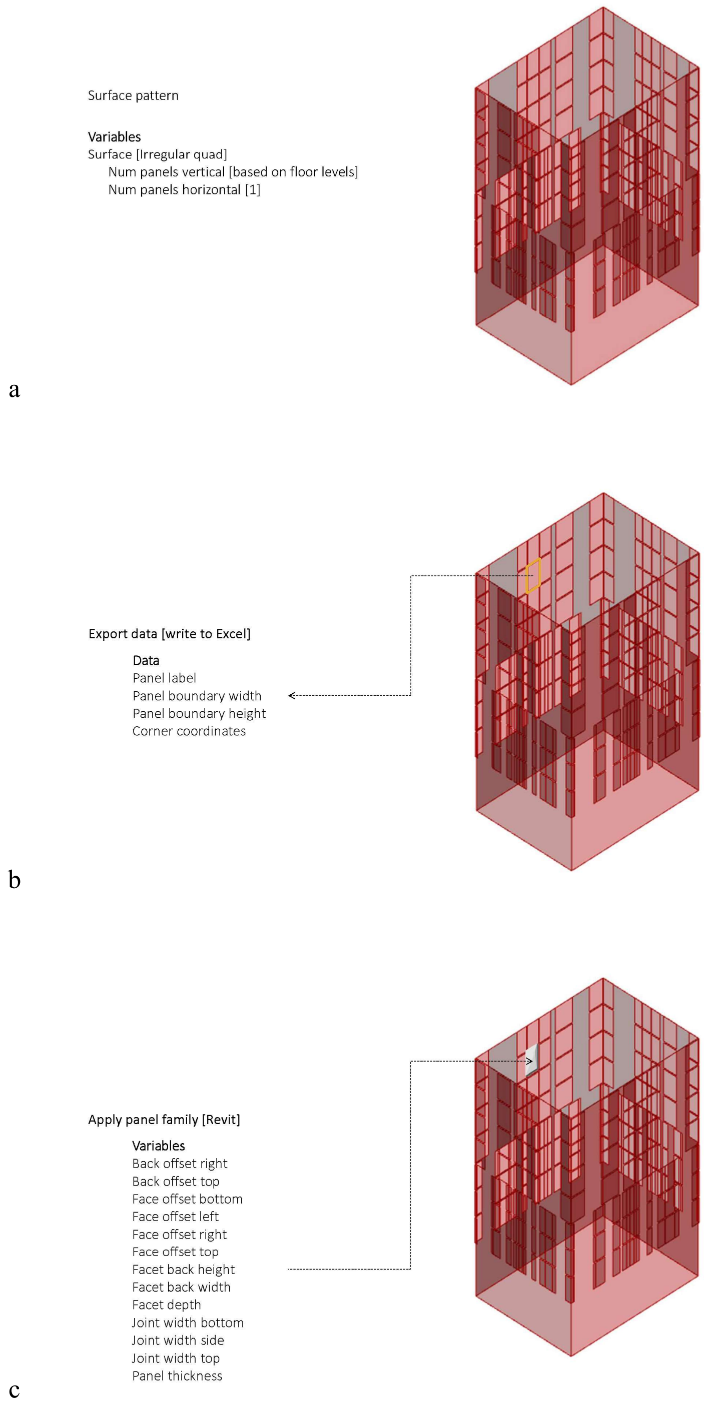



**Figure 88: Suffolk mapping from scaffold to panel – surface pattern (a), export data (b), apply panel family (c)**

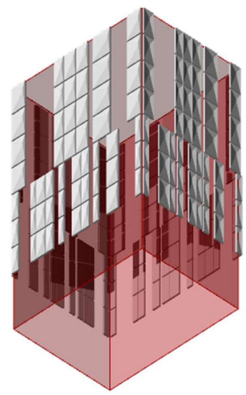


**Figure 89: Mapped Suffolk**

### *5.1.2 From panels to scaffolds*

Models can also be linked from local to global descriptions. Shown in Figure 90, data regarding a custom precast concrete panel is exported from *Revit* via *Dynamo* to *Microsoft Excel* (Table 2). This data is subsequently imported into *Grasshopper* and *Rhino,* wherein panels can be applied to surfaces (Figure 92). This process can then aid in defining variables of scaffold models. Again, the list of data exported from the panel model and the parameters defined within the *Revit* family corresponds to and represents the Fabrication Model exchange following the Precast Detailing stage highlighted in Figure 5. The parametric scaffold still controls the location on the building surface. In this example, however, nominal width and height of each panel is controlled via each individual panel. For panel to scaffold mapping, a new concept is used to control the joint dimension between panels and the relationship between the panels and the buildings structural system – bounding box, shown for individual panel in Figure 91 and its use in the overall façade in Figure 92.

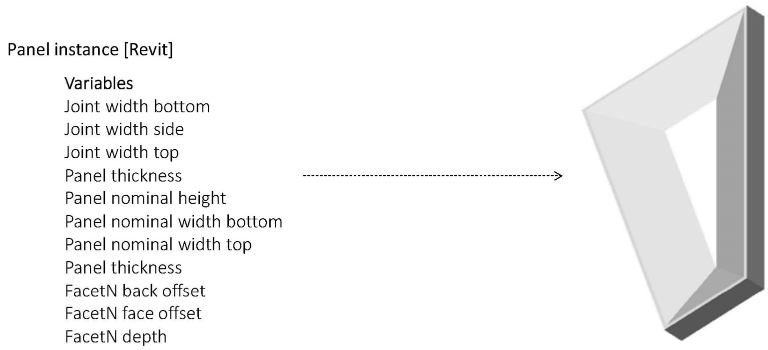



**Figure 90: Example facet + opening panel**

**Table 2: Example facet + opening panel data**

| Parameter | Dimension (in feet) |
|---|---|
| Face offset bottom | 0.667 |
| Face offset left | 0.500 |
| Face offset right | 0.500 |
| Face offset top | 0.667 |
| Facet depth | 0.333 |
| Joint width bottom | 0.333 |
| Joint width side | 0.333 |
| Joint width top | 0.333 |
| Panel nominal height | 6.000 |
| Panel nominal width | 4.000 |
| Panel thickness | 0.500 |
| Window height | 3.000 |
| Window width | 1.250 |
| Window x location | 2.000 |
| Window z location | 3.000 |

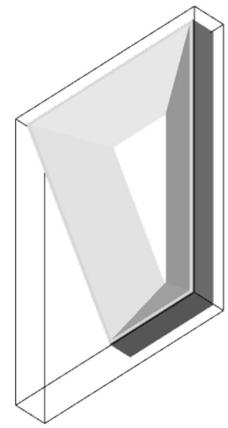


**Figure 91: Example panel bounding box**

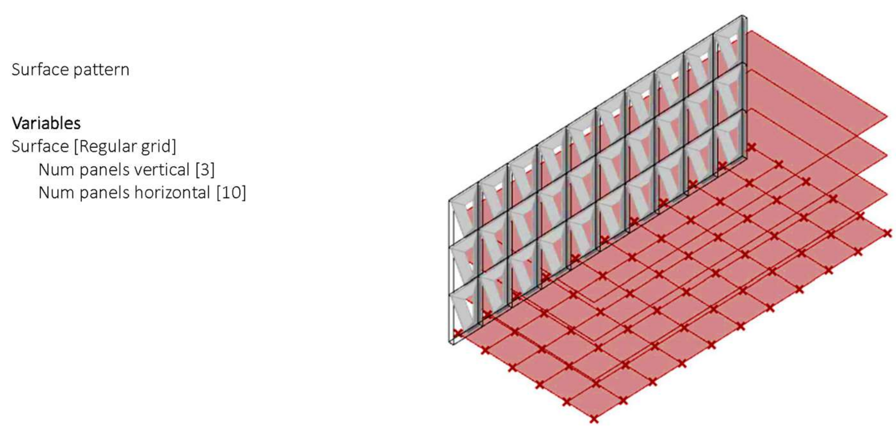



**Figure 92: Direct mapping from panel to scaffold**

#### 5.1.2.1 Example: Armstrong Rubber Company Headquarters

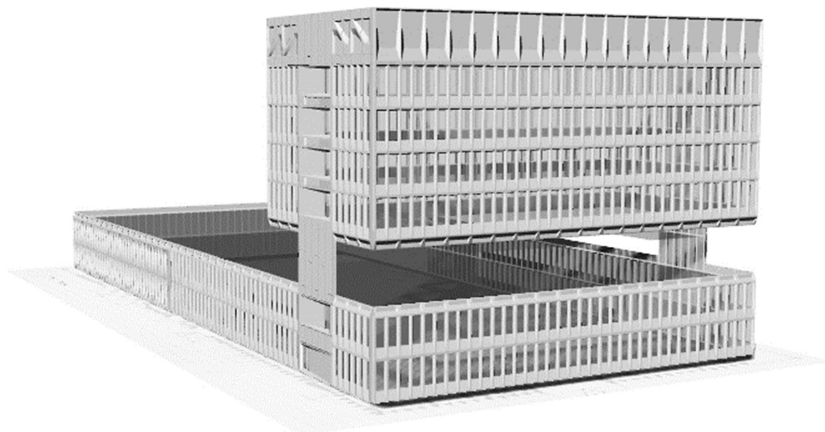


**Figure 93: Digital model of Armstrong Rubber Company Headquarters**

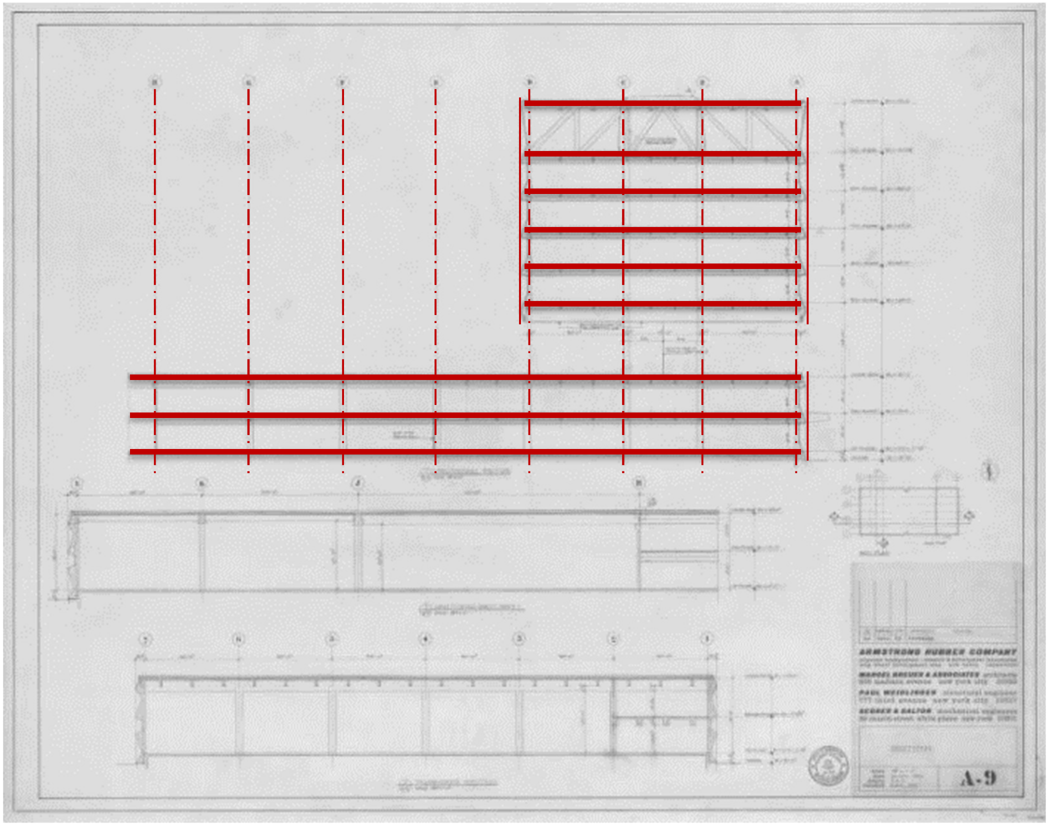
A digital model of Armstrong Rubber Company Headquarters (Armstrong) by Marcel Breuer and Robert F. Gatje is created (Figure 93) in order to demonstrate of direct mapping from panel to scaffold. The building is a noteworthy example of Marcel Breuer's work for a number of reasons: the expressive qualities of the precast panel geometry and façade patterns, demonstration of panel family variations, and the massing of the overall building. Gatje explains the massing further:

> "The company [Armstrong] needed two or three floors of administrative office spaces and assumed it would be placed at the front of the site where it could be seen and admired from the turnpike… Mayor Lee… decreed that nothing short of a ten-story tower (he originally had a vision of eighteen) would do justice to the site. [Breuer] listened to all this carefully and… propose[d] that the office floors be put atop the two-story research and development wing at grade and then – in order to

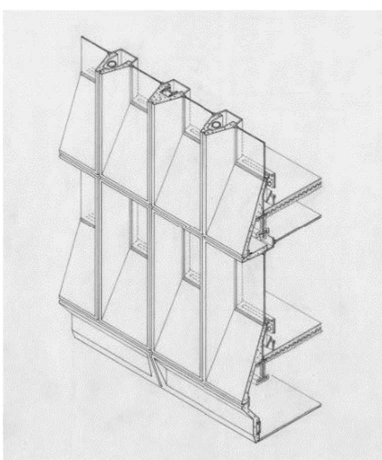
> satisfy [Mayor] Lee – that they be raised clear of the roof below and 'hung from above,' leaving a two-story slot between the two building masses that could be filled with expansion space at a later time." [Gatje, 2000]

Figure 94a highlights the structural grid, floors levels, and exterior wall surfaces – elements typical of architectural projects – indicated in the Armstrong Rubber Company Headquarters construction documents. This geometry is referenced in the creation of a scaffold model for Armstrong, Figure 95, using modelling strategies described in Section 3.1 regarding shape, grid, number of floors, floor-to-floor height, dimension from column centerline to edge of slab, dimension from edge of slab to surface, and dimensions from upper level to top of surface and from lower level to bottom of surface. While defining these relationships is typical, creating parametric models that allow flexible, controlled variation among them is not yet. Figure 94b illustrates the complex panel detailing that is involved for Armstrong despite its relatively straightforward appearance. Modelling strategies described in Section 4.3 aid in the creation of such panels.

There are 5 different panels on Armstrong; flat, negative facet, facet + opening, facet + taper (not explicitly discussed in Chapter 4, but involves combining elements from the facet and taper family models), and gesture. Figure 96 demonstrates how three different panels on the façade of Armstrong can be instantiated from the same panel family model. (The third example, without an opening, suggests the possibility of "turning off" certain available features within panel families. In this case, parameters revert to those for facet instead of facet + opening.)




a



b


c

**Figure 94: Armstrong Rubber Company Headquarters section drawing (a), section axonometric detail drawing (b), and construction photo (c). From [Syracuse University Libraries, 2018]**

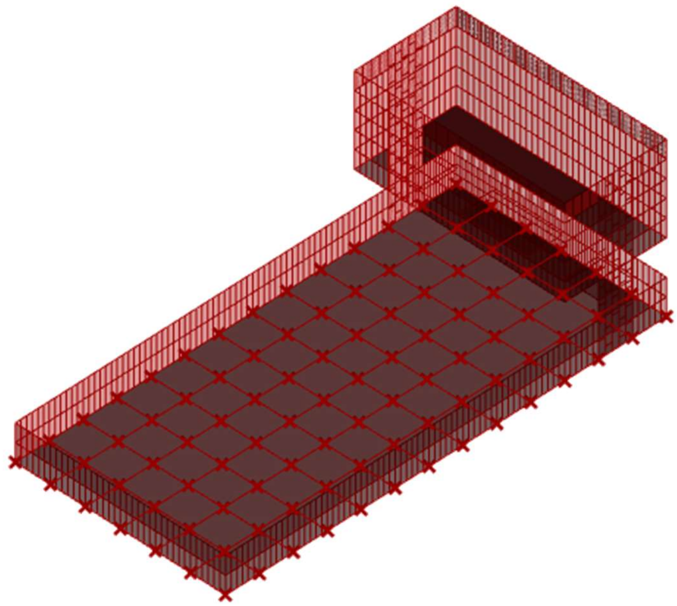


**Figure 95: Armstrong scaffold**

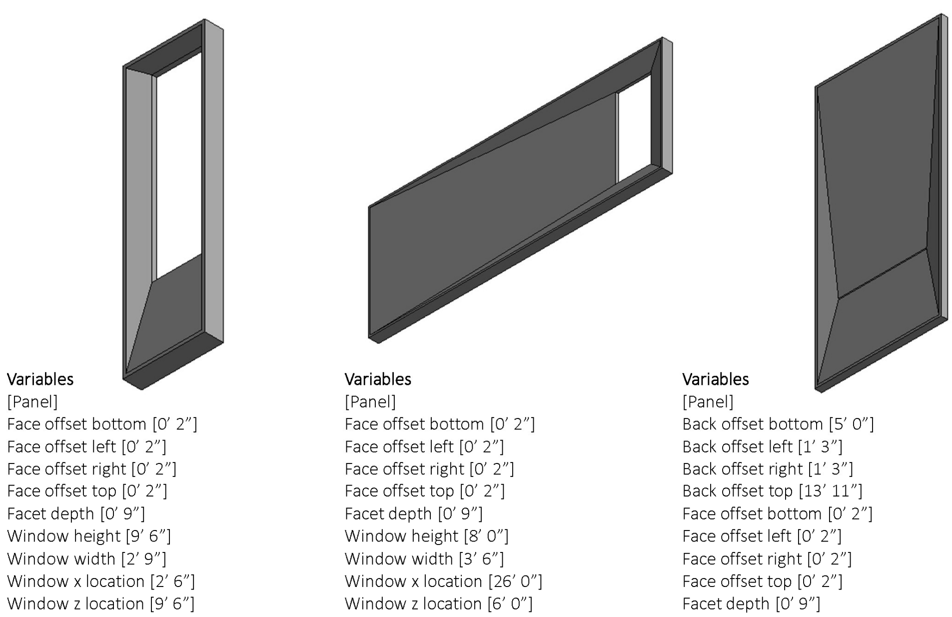



**Figure 96: Example Armstrong panels and variables**

Panels can then be arranged across building surfaces. Figure 97 demonstrates the application of the panels from Figure 96 composed in surface patterns. This is accomplished by defining the dimensions of the surface as a factor of the dimensions of the panel, where:

surface width = panel width x number of panels horizontal

and

surface height = panel height x number of panels vertical

One is then able to flex the size of the surface and the number of panels simultaneously based on the size of the provided panel. Figure 98 demonstrates two further promises of the panel to scaffold – or working from local to global – approach. First, the panel can be applied to non-grid patterns; horizontal running bond is shown in Figure 98a and vertical running bond in shown in Figure 98b. Second, having located panel models across a surface, designers and fabricators can then discuss the relationship between the panels and a parametric scaffold. In the scaffold-to-panel example described in Section 5.1.1, the scaffold determined the size of the panels. In panel-to-scaffold, the panel sizes are set (though the process can iterate and the sizes modified) and the scaffold to adjustable. Further detailed descriptions of the scripts for these models is provided in Appendix G.

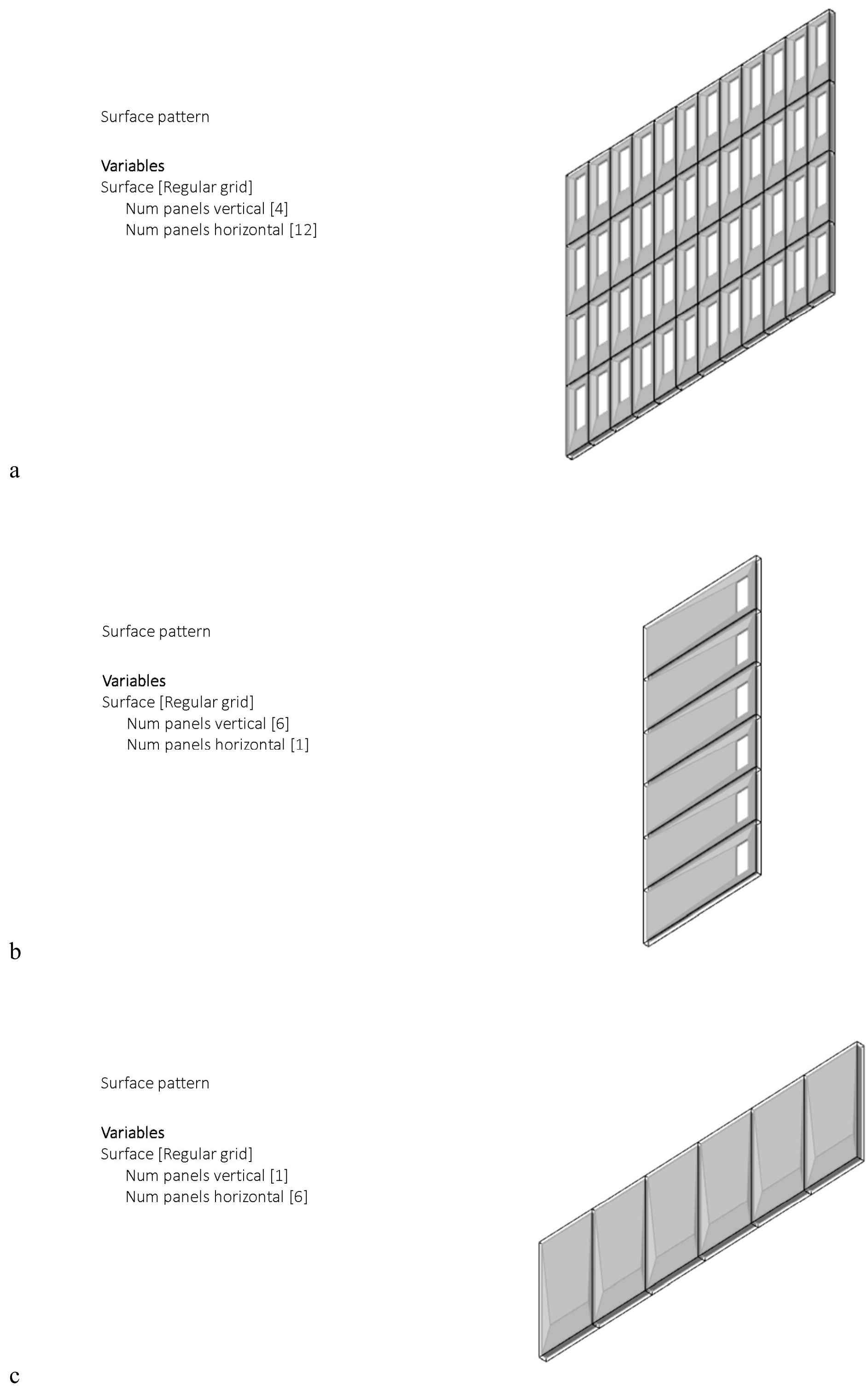


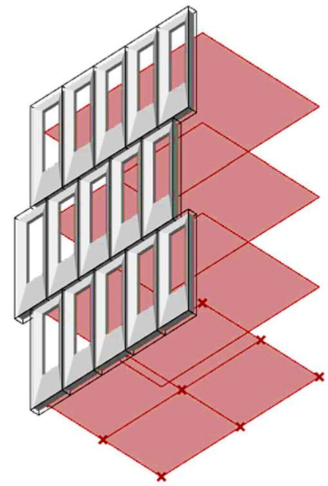

**Figure 97: Armstrong panels applied to surfaces**

Surface pattern

**Variables**
Surface [Horizontal running bond]
  Num panels vertical [3]
  Num panels horizontal [5]

Scaffold

**Variables**
Grid [Regular grid]
  Number of divisions X [2]
  Number of divisions Y [2]
Levels
  Number of floors [3]
  Floor to floor height [14′ 0″]
Surfaces
  Offset in Y direction [1′ 0″]
  Offset in Z direction [2′ 6″]



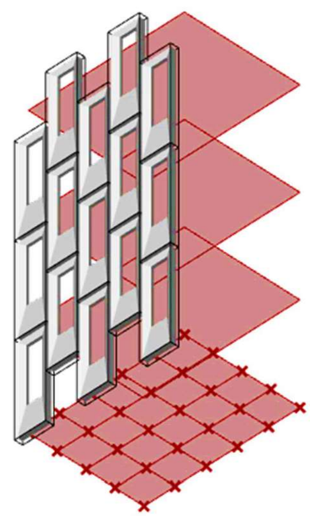
a

Surface pattern

**Variables**
Surface [Vertical running bond]
  Num panels vertical [3]
  Num panels horizontal [5]

Scaffold

**Variables**
Grid [Regular grid]
  Number of divisions X [5]
  Number of divisions Y [4]
Levels
  Number of floors [3]
  Floor to floor height [17′ 0″]
Surfaces
  Offset in Y direction [1′ 0″]
  Offset in Z direction [2′ 6″]



b

**Figure 98: Armstrong panel patterns and scaffolds – horizontal running bond (a) and vertical running bond (b)**

## 5.2 Indirect

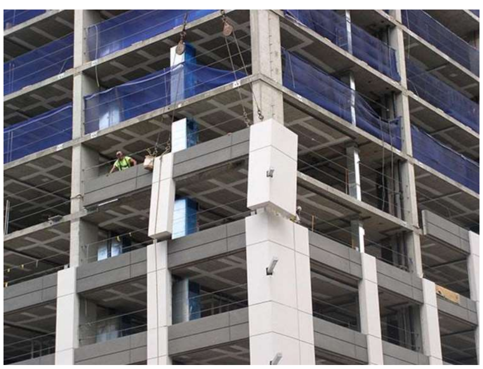
Unlike the buildings and models described above, there are some architectural precast concrete façades which do not permit direct relationships, or simple mapping, between global and local descriptions. Such indirect maps require additional layers of information in order to coordinate global and local descriptions. Two such indirect scenarios are discussed: panelization and patterns across panels. It should be noted here as well that the term "indirect" is used conceptually, denoting a nonlinear relationship between façade features and panels. It is still the goal of this research to allow direct exchanges of model data between actors, even – or perhaps especially – for relationships that are indirect.

### *5.2.1 Panelization*

Similar to the situation described for Shands in Section 4.4, patterns perceived on building façades do not necessarily dictate joints between individual precast pieces. Precasters, balancing many fabrication and assembly issues, often prefer larger panels than those that might be suggested in design descriptions. This could result in "joining" adjacent panel boundaries together. This phenomenon can be observed in Adtran Corporate Headquarters by Cooper Carry (Figure 99a), Philadelphia Police Department Headquarters (Roundhouse) by Geddes, Brecher, Qualls and Cunningham (Figure 99b), Clark and Grand Hotels by HOK (Figure 99c), California State University San Bernardino College of Education by LPA (Figure 99d), Gordon Food Service Corporate Headquarters by Integrated Architecture (Figure 99e), and Teen Living Programs (Belfort House) by Hartshorne Plunkard Architecture (Figure 99f). In these cases, architectural features that may have been defined as joints between panels in design intent documents become reveals (or panels could merge and the joint erased as will be discussed in the special case of Atlanta Public Library). Conceptually, this requires managing additional layers to control both surface patterns and panelization patterns.

a

b



c

d

e

f

**Figure 99: Panelization in precedent buildings ***

#### 5.2.1.1 Example: Philadelphia Police Department Headquarters (Roundhouse)

Philadelphia Police Department Headquarters (Roundhouse) by Geddes, Brecher, Qualls and Cunningham in Figure 99b demonstrates panelization clearly. If one were to create a scaffold model for the building in the background of the construction photo, it most likely would describe three panel boundaries – one for each level of the building. However, we can see from the panel being lifted into place in the foreground that the panels were actually fabricated as three-story tall pieces. In addition to the façade, the structural system of Roundhouse is precast concrete with some cast-in-place concrete. Panel have deep facets and openings across an undulating, curving form. [Hahn, 2016]

Layers of data required for coordination of panelization are diagrammed in Figure 100. First, the panel boundaries/surface pattern defines the design intent. Next, data regarding panel features is extracted from customized individual panels. Then, a distinct panelization pattern is applied. Each of these layers is projected back to the building surface; illustrated on a flat surface in Figure 101 and on the curvaceous building mass in Figure 102. Further detailed descriptions of the scripts for these models is provided in Appendix H.

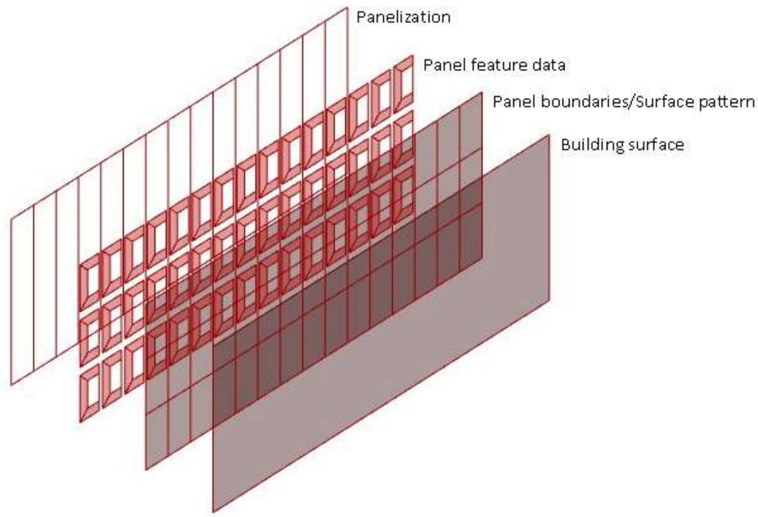



**Figure 100: Layers of panelization data for Roundhouse**

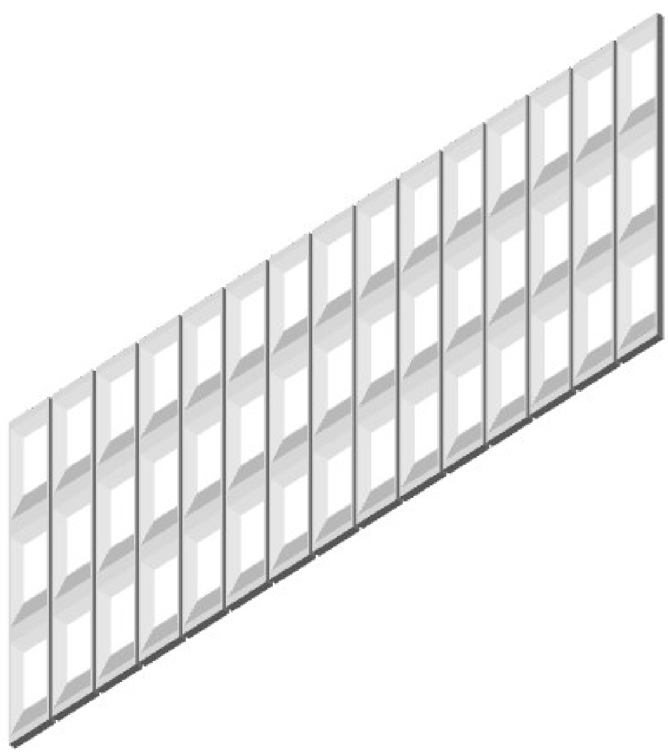


**Figure 101: Roundhouse panelization**

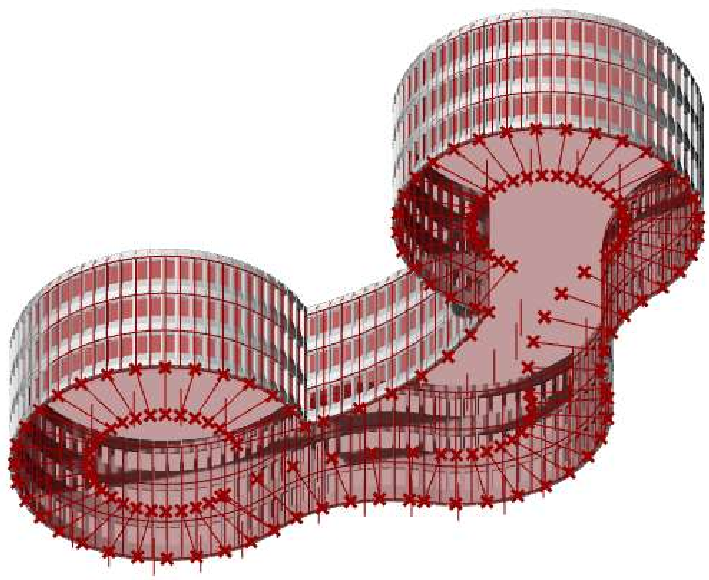


**Figure 102: Mapped panels and mass model of Roundhouse**

### 5.2.1.2 Special case: Atlanta Public Library

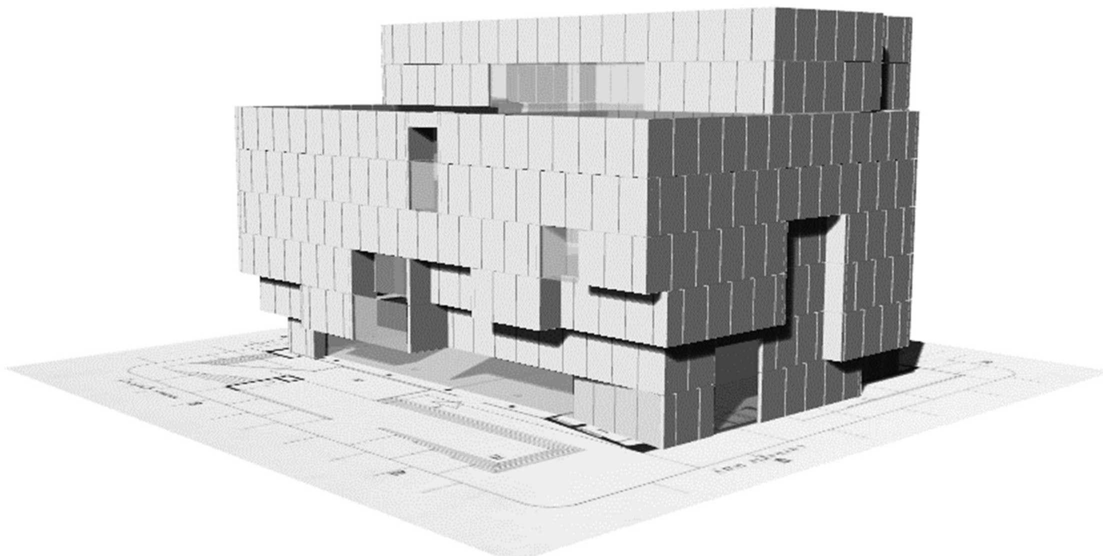


**Figure 103: Digital model of Atlanta Public Library**

Completed in 1980, the Atlanta Public Library was one of the final buildings that Marcel Breuer designed. Breuer had actually officially retired from the office during its construction, handing responsibility for the project to one of the firms' partners, Hamilton P. Smith. [Gatje, 2000] Almost immediately, the building form and material selection was controversial:

> "The architects were called on to justify the selection of precast concrete instead of natural stone for the exterior; they pointed out that in addition to the impact on the construction budget, precast concrete panels could be given the special shapes called for by the design – for example, the recessed windows with splayed reveals. The panels could be cast in L-shape, and therefore 'turn the corner' (not possible in

natural stone), and could be cast large enough for the 15-foot floor-to-floor vertical dimension." [Hyman, 2001]

There has been research contemplating the effects, composition, and logic of the library's façades, namely Wright and Bafna (2014) and Bafna (2013). The building, its significance to the history of both modern architecture and Atlanta, and its future as a landmark, have recently become part of public conversation again as the library prepares for a renovation. [Keenan, 2018a and Keenan, 2018b] This work endeavors to use some of the digital modelling techniques described herein as an analysis tool for the façade patterning. Three specific aspects of the pattern – which have been illusive to interpretation and may be misunderstood as happenstance – are of particular interest:

- The location of large openings
- The relationship between the large openings and the surface pattern
- Joining or splitting of panels which "disrupts" the surface pattern

A digital model of Atlanta Public Library is created (Figure 103). As a demonstration of using digital tools for analysis, this study focuses on one surface of the southwest façade of the library, highlighted in Figure 104. An initial step was to evaluate the panels to determine types. For the purposes of this study of the surface pattern, all panels are assumed to be flat. There are, therefore, ten different panel types based on panel widths: standard flat panel, standard corner panel (long leg), standard corner panel (short leg) / half panel, two-thirds panel, end of adjacent panel, extended full panel, extended half panel, L shape elevation panel, perpendicular panel, and lintel panel. Locations of panels of each type are illustrated in Figure 105.

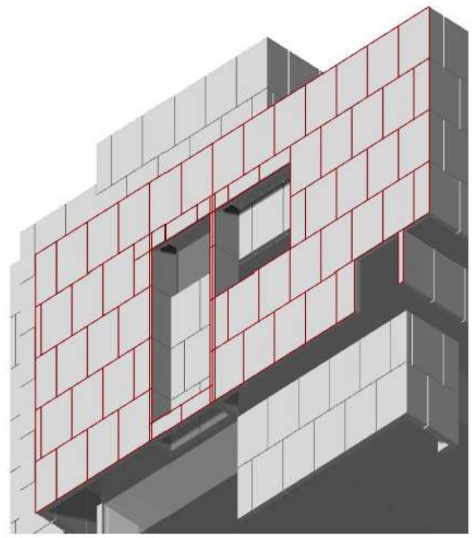


**Figure 104: Atlanta Public Library study surface**

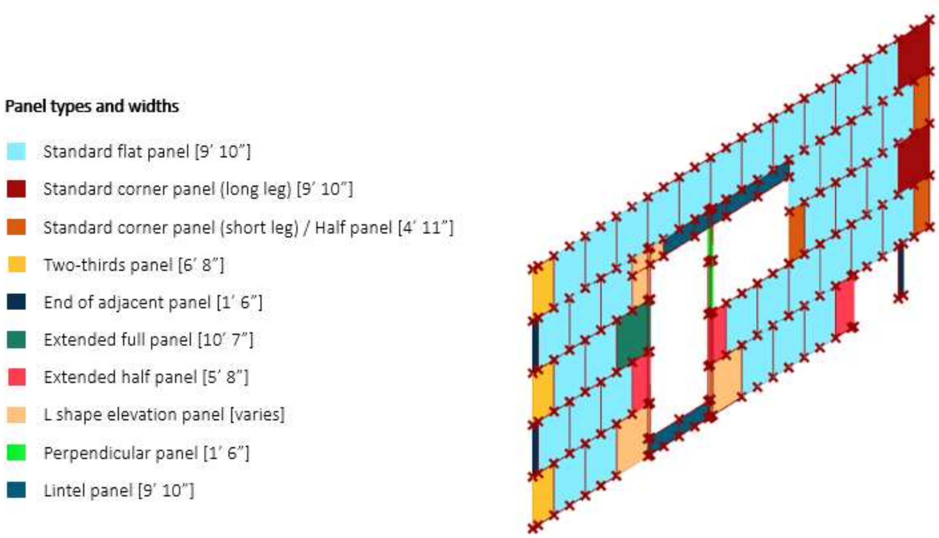
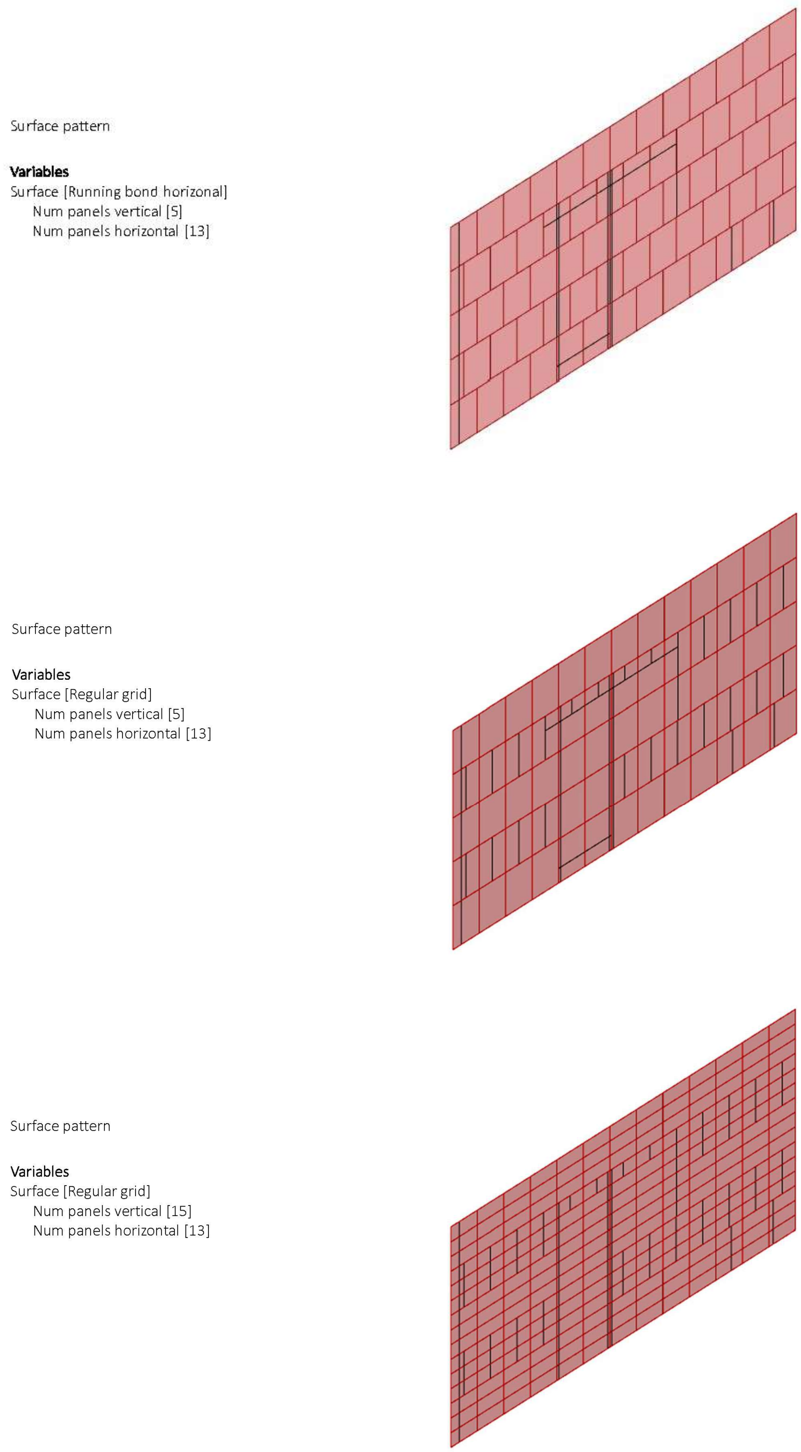



**Figure 105: Atlanta Public Library study surface panel types and widths**

Looking at the building, the most obvious surface pattern is horizontal running bond. For the surface in question, the pattern is five panels in the vertical direction and thirteen (13) panels in the horizontal direction. Depicted in Figure 106a, overlaying this pattern on a diagram of the as-built façade pattern, it is clear that there are some disparities. First, in order for the pattern fit properly on the surface, it needs to be extended beyond the edge (note the black line on the left of the figure which is the extent of the surface in this study). Given other misalignments, various other patterns are examined. Figure 106b applies a regular grid to the surface. This is clearly not the solution either, but does perhaps give a clue about how the relationship between of the large openings and the pattern. This is explored further in Figure 106c, which divides the surface into an increased number of horizontal panels; from five to fifteen. This pattern registers with the top and bottom of the large openings.

Next, the number of vertical divisions is explored. First, in Figure 107a, a panel is divided into twelve (12) vertical strips. This pattern is then applied to each of the original horizontal running bond panels, depicted in Figure 107b. A composite of each of these patterns is represented by a regular grid of fifteen (15) vertical panels and one-hundred-fifty-six (12 x 13 = 156) horizontal panels, Figure 107c.

Analysis of the façade pattern of Atlanta Public Library has shown that it is this grid that establishes the locations of the large openings in the façades. Shown in Figure 108a, the larger openings are defined by selecting four nodes of the grid to define rectangular regions. The original running bond pattern is then applied to the surface (Figure 108b) and the regions are removed from the surface (Figure 108c). Of course, this example demonstrates the regions in the existing building, though the modelling logic is intended to allow a variety of design options to be explored.




a

b

c

**Figure 106: Atlanta Public Library basic surface patterns**

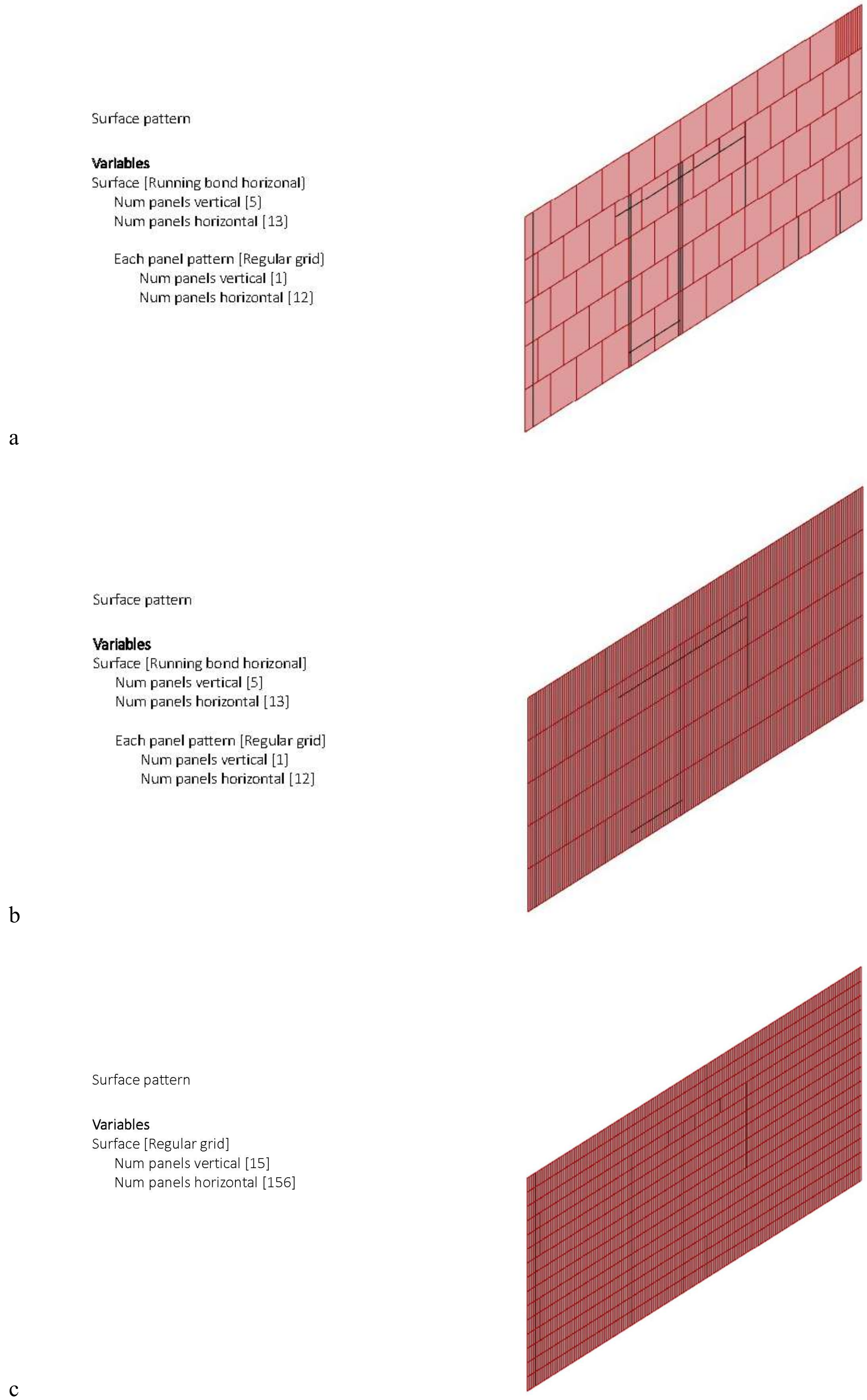
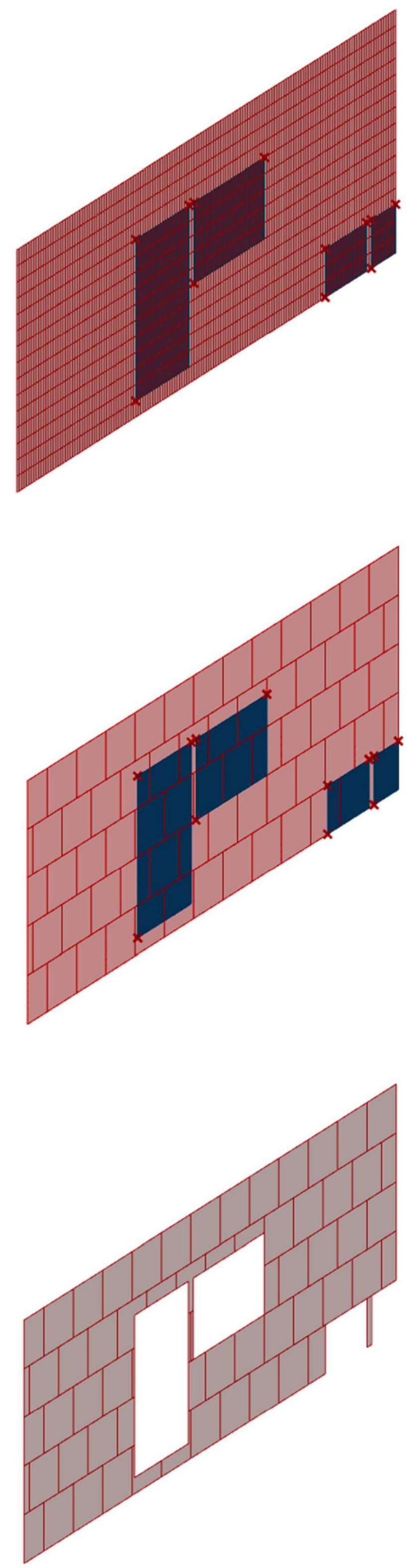



**Figure 107: Atlanta Public Library composite surface patterns**



a

b

c

**Figure 108: Atlanta Public Library regions defining large openings**

When this surface pattern is iterated through the described scaffold to panel mapping technique, the majority of the panels reflect the built work. However, shown in Figure 109, there are some anomalies. In each of these cases, the logic of the digital model suggests a certain panel shape while a different panel was built. It is suggested that this is because of both design and fabrication issues of the "direct" panels. In the T shape, Figure 110a, the thin vertical would be too fragile, so it is split into two; a control joint is created. For the vertical piece just below the T, Figure 110b, these pieces may be deemed either too thin for fabrication or the occasion of a joint in this location may have been too distracting from a design perspective, so the panels are joined. This panel is also perpendicular to the surface in this study, extending into the mass of the building; a joint there would not make sense. There is also a standard size panel, Figure 110c, that merges with an adjacent thin panel to create an "extended full panel."

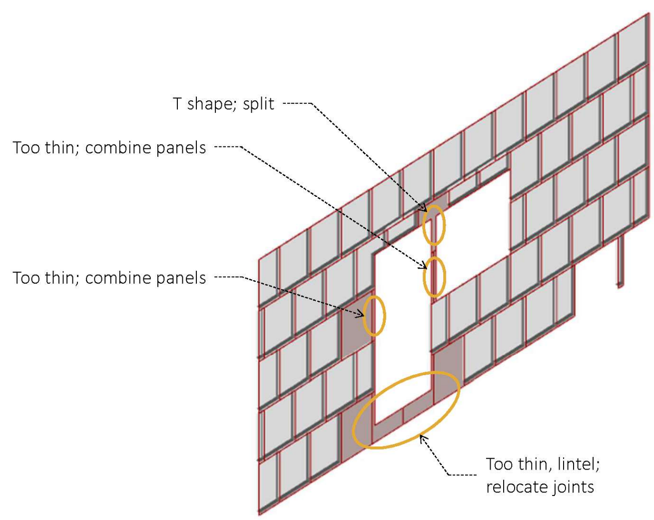
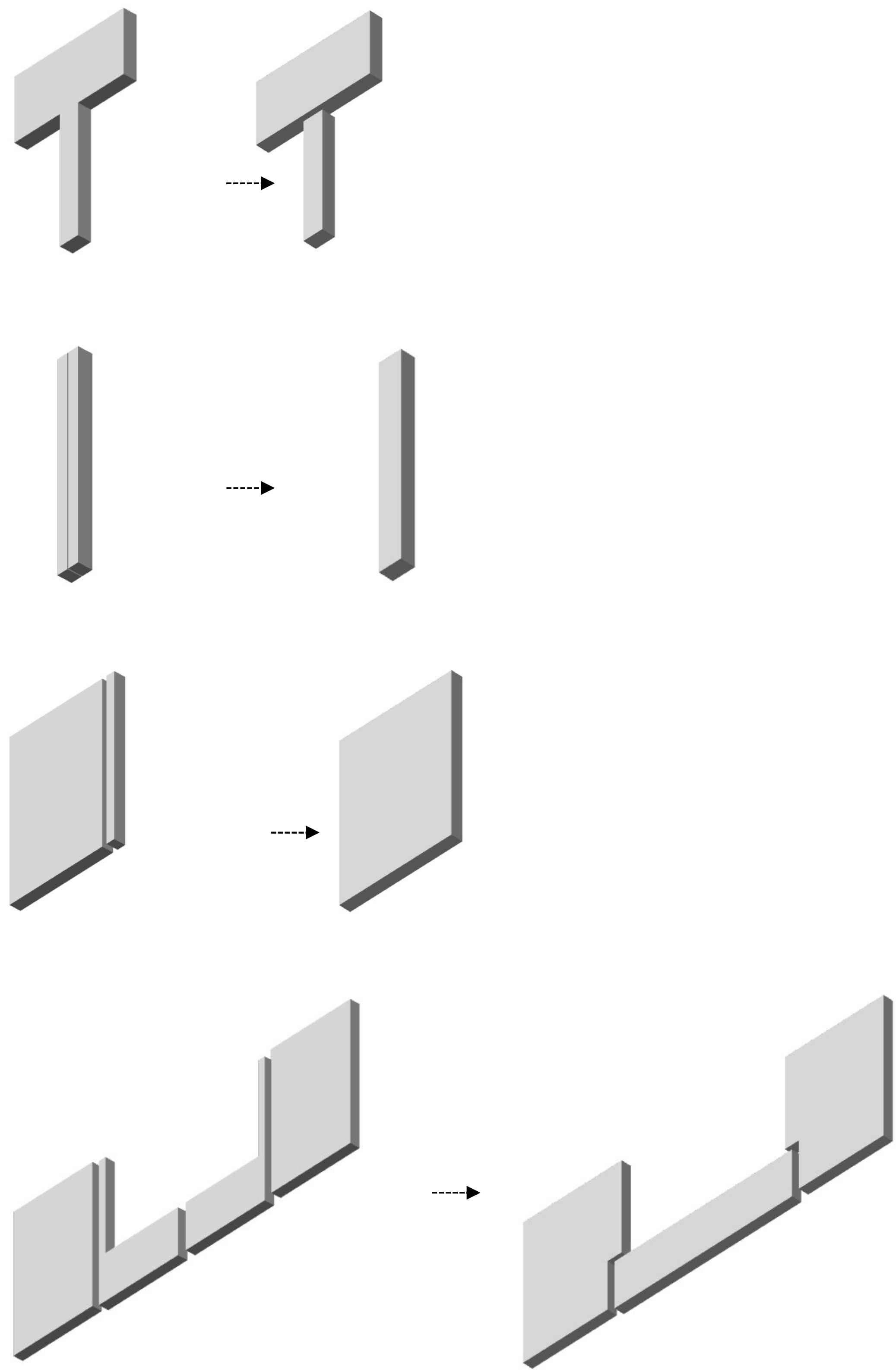



**Figure 109: Issues with direct linking of certain panels**



a

b

c

d

**Figure 110: Combining and splitting panels**

The panels depicted in Figure 10d reveal a logic for a condition that may seem like the most illogical one on the entire façade of the building. The compositional result of overalying the location of the openings and the surface pattern creates two mirrored L-shape panels with thin vertical extentions. Similar to the T-shape panel described above, it is imparitive to add a control joint to these panels. Rather than have a small itoslated vertical piece, the vertical elements are trimmed from the L-shape and merged with the adjacent standard panels and the condition as built results. After each of these scenarios is resolved, all panels can be instantiated into the coordinated model depicted in Figure 111.

The example of the Atlanta Public Library is included in the dissertation as a demonstration of the potential of interaction between designer and fabrictor, specifically regarding conflicts that the surface pattern reveals regarding the constructability of certain panels. When a horizontal running bond pattern is applied to the surface of the library mass, shown in Figure 109, there are some anomalies with the as-built. To mediate various fabrication issues – which could be discussed and deliberated using the describing mapping procedures – steps can be taken to modify panels. The façade design of the Atlanta Public Library appears to incorpoate such knowledge which Breuer's office had gained through years of designing and working with fabricators of precast concrete, perhaps rejecting default solutions in order to express alternative material effects. The described mapping procedures, aided by parametric models, seek to empower those that may be new to precast façade design with similar knowledge.

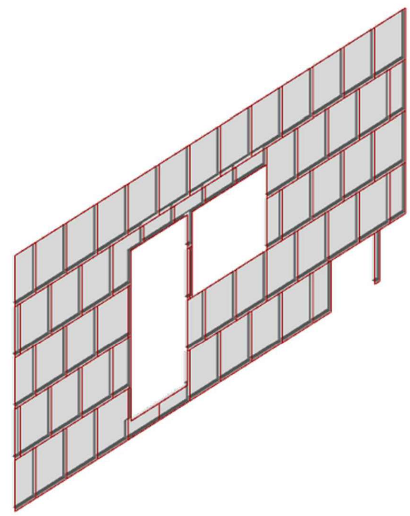


**Figure 111: Atlanta Public Library southwest façade panels**

### *5.2.2 Patterns across panels*

Hinted at in Section 4.3.16, there are some building façades where a pattern, texture, relief, or similar "gesture" may cross over two or more panels. This is noted in 150 Rouse Boulevard by Digsau (Figure 112a), Douglas L. McCrary Training Center by TOWNES + architect (Figure 112b), Hotel Residencial Nakâra by Jacques Ferrier Architecture (Figure 112c), Internal Revenue Service Center by HOK and BNIM (Figure 112d), Nanyang Technological University Learning Hub (The Hive) by Heatherwick Studio and CPG Corporation (Figure 112e), and Perot Museum of Nature and Science by Morphosis (Figure 112f). These buildings' surface patterns may be indifferent to panelization, expressing distinct layers of composition.

a b c

d e f

**Figure 112: Patterns across panels in precedent buildings ***

5.2.2.1 Example: 150 Rouse Boulevard

150 Rouse Boulevard by Digsau in Figure 112a is an interesting example because there are clearly multiple layers of patterns occurring and controlling various characteristics of the façade; the architect describes these as "multiple textures [to] create a large-scale pattern overlaid over the pattern formed by the construction joints of the panels." [Digsau, 2018] These layers are diagrammed in Figure 113. Unlike Roundhouse, the panelization pattern is clear. However, there are two additional layers of features that violate the panel boundaries. First, a staggered quad pattern describes textured relief areas. Then, openings are randomly populated across the surface. Again, all of this layered geometry is described and projected back to the building surface. Variations are illustrated in Figure 115, wherein openings and relief areas are varied while panelization remains constant. Further detailed descriptions of the scripts for these models is provided in

Appendix I. Clearly, an enormous amount of designs are possible. The focus of Chapter 6 will be how these maps allow for such exploration as well as fabricator coordination.

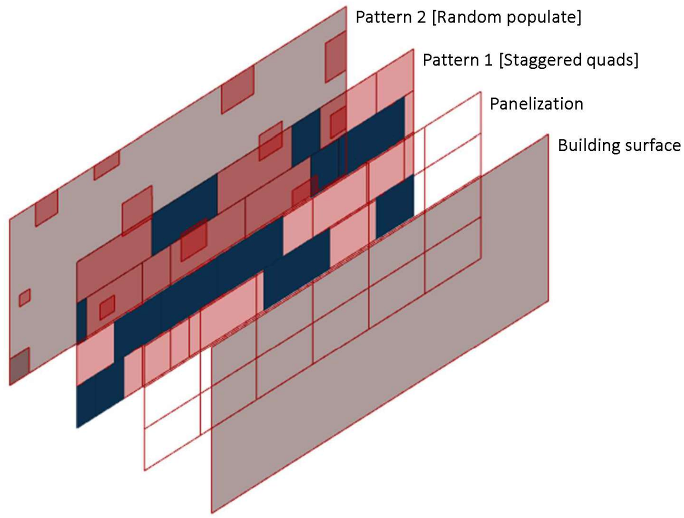



**Figure 113: Layers of patterns across panels for 150 Rouse Boulevard**

**Figure 114: Construction photo of 150 Rouse Boulevard from [Digsau, 2018]**

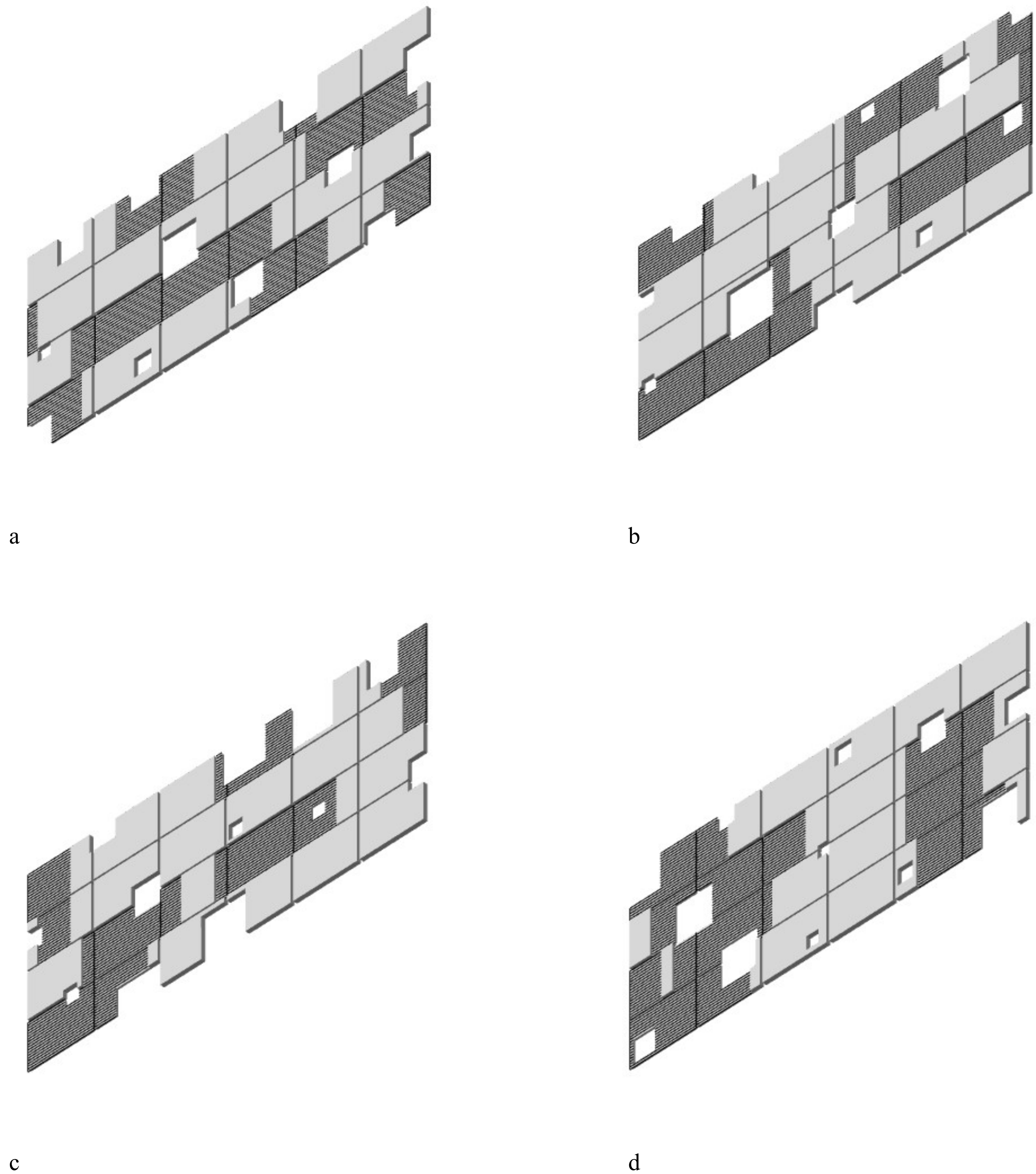



**Figure 115: 150 Rouse Boulevard patterns across panels variations**

This chapter has described methods for linking global and local parametric digital models of precedent precast concrete façades. Two main categories were presented: direct mapping and indirect mapping. Within each of these categories, two types were discussed: direct from scaffolds to panels, direct from panels to scaffolds, indirect panelization, and indirect patterns across panels. It is not proposed that a given project uses one of these types exclusively. Rather, any or all of these methods could be used iteratively during the design process to coordinate among various scaffold and panel models. While this chapter has focused on existing precedent buildings to uncover mapping strategies, Chapter 6 will apply these techniques to novel student design proposals to postulate the effects of this process on design and fabrication coordination.

# CHAPTER 6. APPLICATION

As the functionality of linked digital models is established in Chapter 5, the main question that this chapter seeks to answer is: How does this proposed future state effect design and fabrication coordination? Three projects from a design studio in the Master of Architecture program in the School of Architecture at Georgia Tech are presented. The studio, taught by Professor Tristan Al-Haddad, was focused on developing proposals for a large-scale, mixed-used, precast concrete building in midtown Atlanta, adjacent to the High Museum. The building would replace and expand the Arts Center MARTA (Metropolitan Atlanta Rapid Transit Authority) Station. An additional design challenge was for the program to change over time; originally a parking garage, then – as our culture hypothetically becomes less dependent on cars – adapting to a hotel. Students realized quickly that the modules for parking garages, hotels, and standard structural precast beams are in close range. Designs included precast proposals for both structural and architectural application. The focus here continues to be architectural precast, though the interface of façade panels and structural precast in referenced. In addition to documenting and creating linked, parametric, digital models of the designs, structured interviews with each of the student teams were conducted. Transcripts of these conversations are included in Appendix J; these inspire the below described design and detailing variations using digital modelling techniques and expert knowledge previously documented.

## 6.1 Scheme 01

### *6.1.1 Concept*

**Figure 116: Student Scheme 01 rendering**

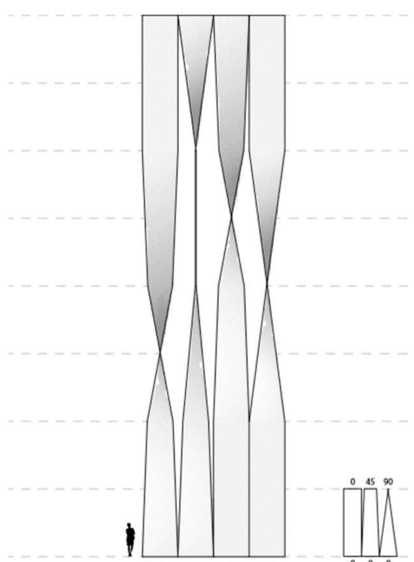



**Figure 117: Student Scheme 01 façade concept**

Regarding the design of their building, the student team for Scheme 01 noted:

> "Our building staggers, so we wanted to play with the light that got into the different rooms of the hotel. We wanted a façade that could be broken down in a small number of panels… A stripe of the building is a bit more open is where the public space is... [we] pulled the façade up over the ground floor so it is all open to the public."

This playfulness took the form of twisting façade panels as shown in Figures 116 and 118. Similar to precedent projects, a scaffold model (Figure 118) and panel frame (Figure 119) for Scheme 01 are developed. The program of the building – either parking garage or hotel – dictates, to a large degree, the building form as well as a number of the variables. For Scheme 01, the twisting panels can vary in the amount that they are twisted. This is achieved through various regions across the façades, wherein different regions dictate different amounts for the "twist factor" of panels.

### *6.1.2 Models*

The façade for Scheme 01 is one wherein the surface pattern – even though it is a regular gird – is not dictated by the dimensions of the building structural grid. Figures 120a and 120b illustrate an enlarged typical map. At this level of detail, the model can explore an issue previously mentioned in Section 3.1; the relationship between panels and structural system/slab in both y and z directions. This will allow, in Scheme 01, the panels to hang "outboard" of the building enclosure and to be lifted above the ground level.

Scaffold

**Variables**
Shape [profile]
  Bay depth [60]
  Bay width [26]
Grid [Irregular grid]
  Number of divisions [varies]
Levels
  Number of floors [10]
  Floor to floor height [15]
Surfaces
Regions

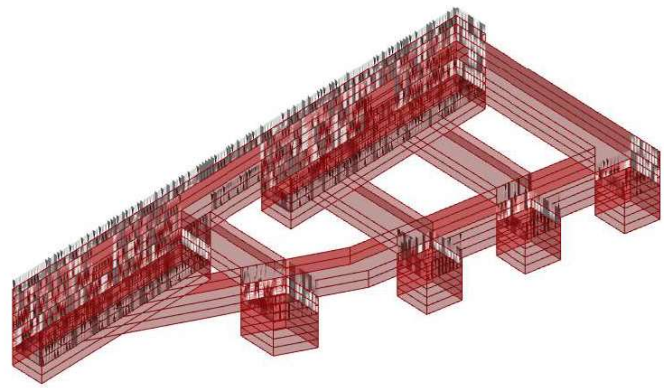


**Figure 118: Student Scheme 01 scaffold**

Panel_Twist
  Label :
  Joint width bottom :
  Joint width side :
  Joint width top :
  Panel nominal height :
  Panel nominal width :
  Panel thickness :
  Twist factor bottom :
  Twist factor top :

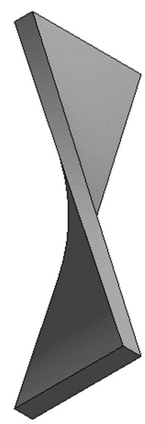
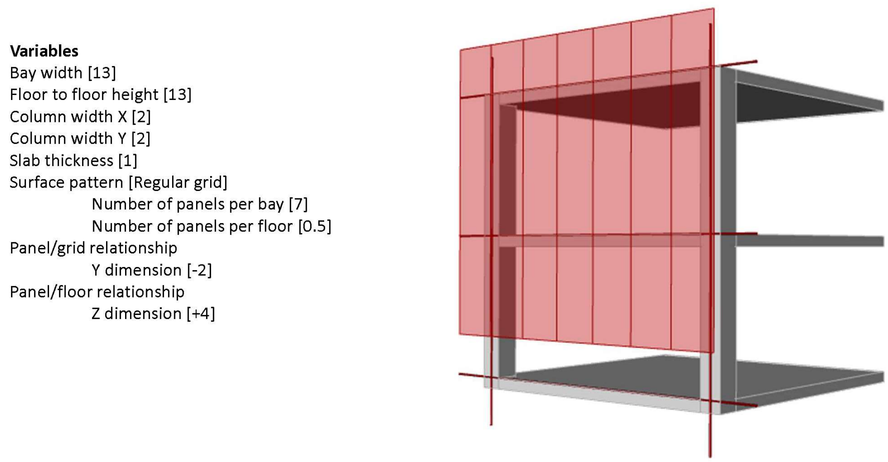
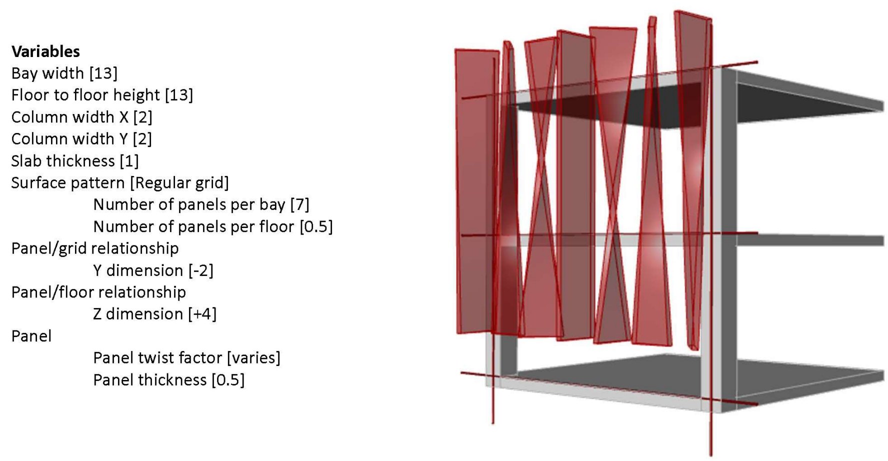


**Figure 119: Knowledge frame for twisted panel**




a




b

**Figure 120: Student Scheme 01 mapped scaffold – surface pattern (a) and panels (b)**

### *6.1.3 Design and detailing considerations*

There are two parameters critical to this scheme – the amount of twist and the height of panels – which greatly effect both design and fabrication. A model is created (Figure 121) to focus on exploring variations of these factors. In the current model, twisting is controlled by rotating the top and bottom of the panels. Rotation is limited to 90, 45, 0, -

45, or -90 degrees (where 90 is perpendicular to the building surface and 0 is in the plane of the building surface). Panel variations using these twist increments are shown in Figure 122. The model could be adjusted so that twisting is further limited; say, to just 45, 0, or -45 degrees. Or, if it was determined that more twisting is possible (perhaps through 3D printed formwork), additional increments could be added. The amount and variation of twisting would clearly have an effect on the levels and quality of light entering the building; a factor that the student team was initially interested in exploring.

In conversations with the student team, they depict the panels as two-stories tall (shown in Figure 121). While this may be possible to fabricate, it may be determined that shorter panels would be more ideal. The coordination model readily allows the panelization to be adjusted in any number of ways, similar to the project discussed in Section 5.2.1. The relationship between the panels and the building structural system/slab can also continue to be examined.

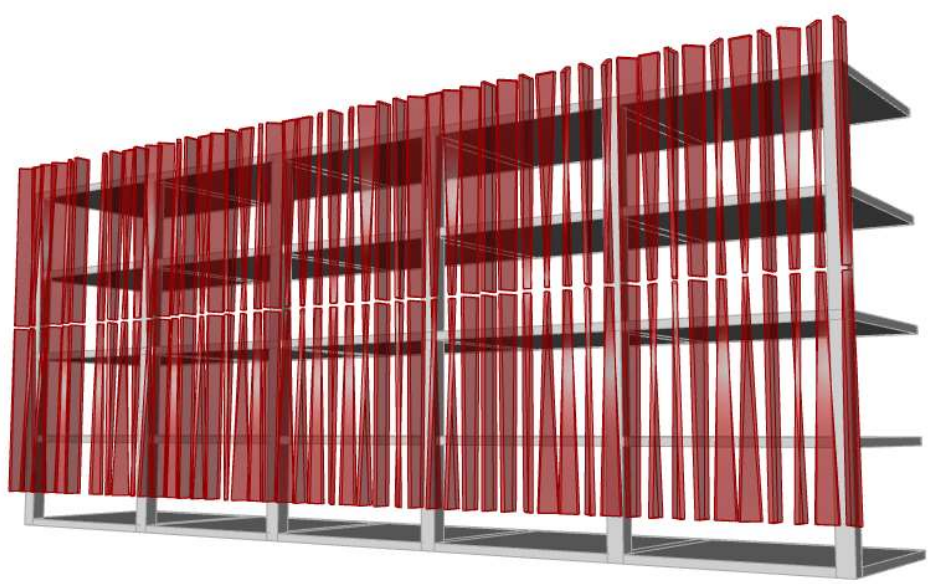


**Figure 121: Student Scheme 01 coordination model**

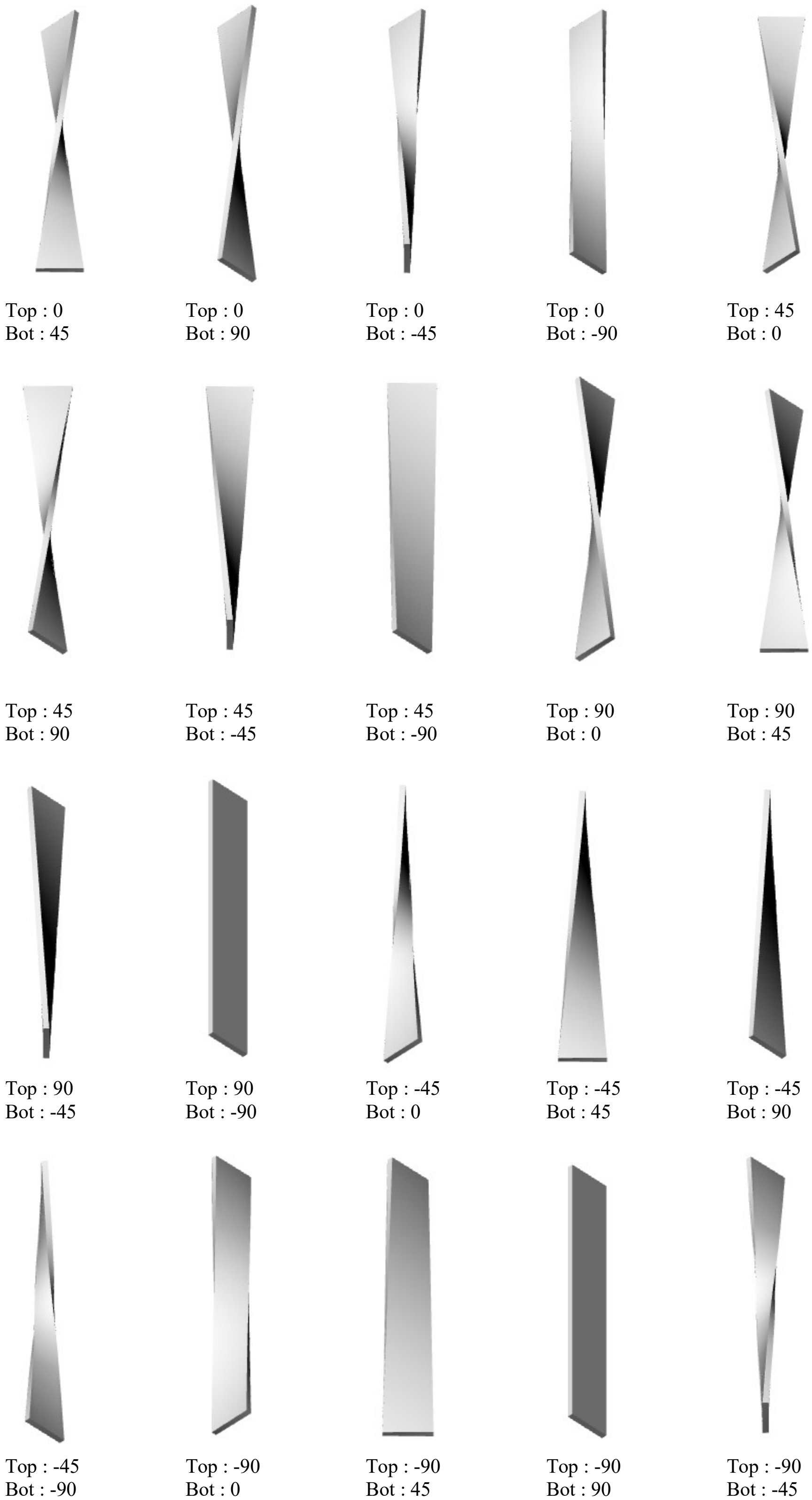



**Figure 122: Twisted panel variations**

## 6.2 Scheme 02

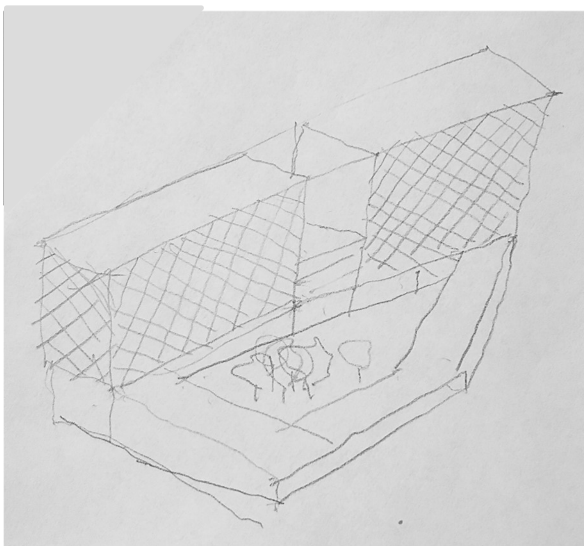
### *6.2.1 Concept*


**Figure 123: Student Scheme 02 rendering**

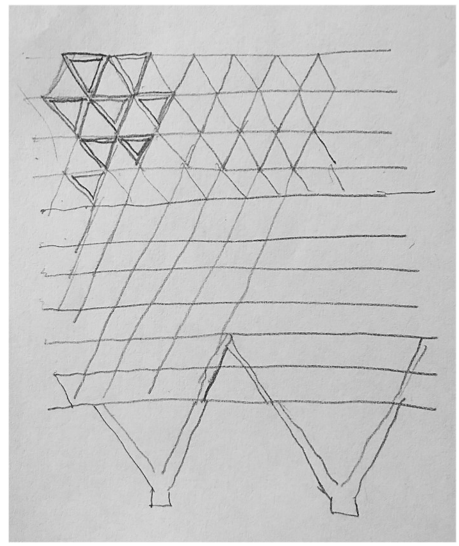
Regarding the design of their building, the student that designed Scheme 02 noted:

"As a hotel, I was thinking that the building should have character. I was trying to unify the structure and façade system. It is a diagrid and triangular panels."

A diagonal pattern controls the layout of the façade. The panels are triangular in profile and, in addition to being cladding, are structural members supporting precast slabs. The relationship between the diagonal pattern and the triangular panels is clearly shown in the sketches in Figure 124a and 124b, where a diagonal pattern in both directions – in addition to floor levels – defines triangular panels. A scaffold model (Figure 125) and panel frame (Figure 126) are developed. The scheme embraces a more standard “podium and tower” mass than that of Scheme 01.



a



b

**Figure 124: Student Scheme 02 sketches – axonometric (a) and elevation (b)**

### *6.2.2 Models*

There are some adjustments to the previously discussed rectangular facet + opening panel that need to be made to the model in order for it to function for the triangular pattern of the façades of Scheme 02. Of course, there is not a “bottom” for the facet and window, so those parameters are removed, leaving top, left side, and right side. There is also some finessing required at the “nodes”; the point at which multiple panels join together. Nodes have a straightforward relationship with rectangular panels. When triangular, panels meet at a point. In many cases, perhaps especially when the panels are structural, this will not be an adequate connection. The panel frame depicted in Figure 126 has a slot "node profile" to facilitate node detailing. This will be discussed further below.

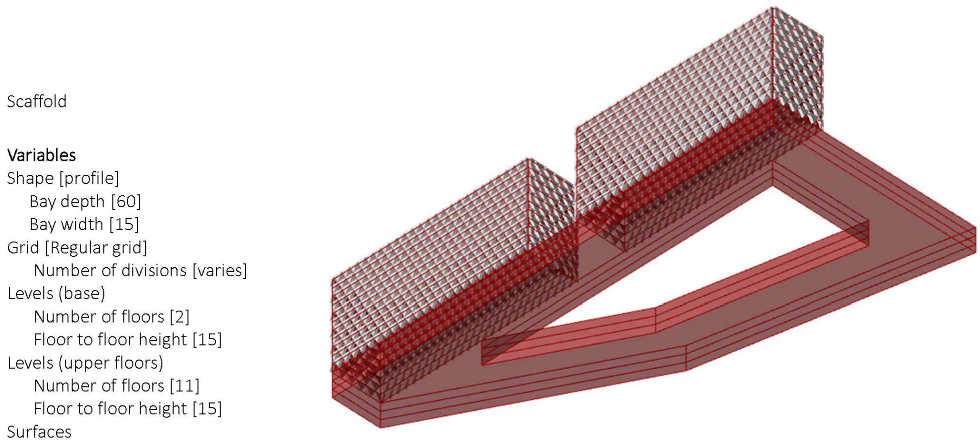



**Figure 125: Student Scheme 02 scaffold**

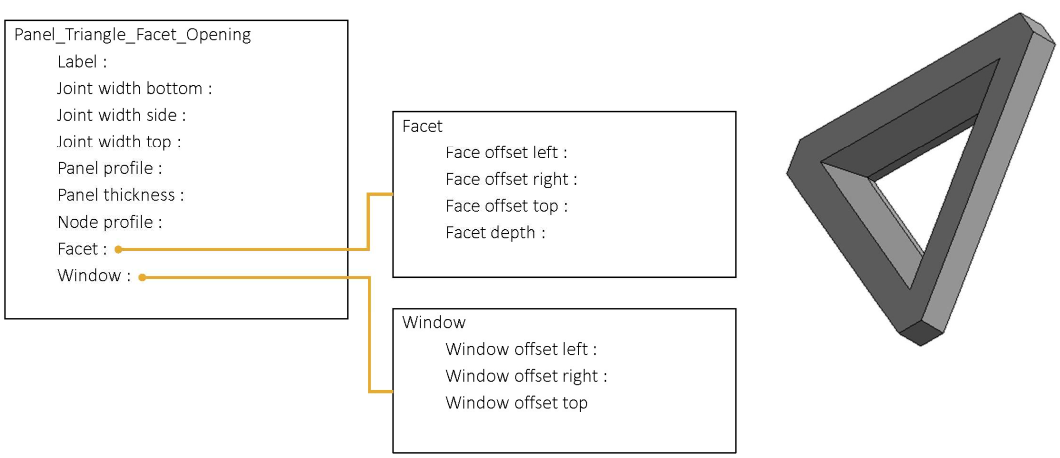



**Figure 126: Knowledge frame for triangular facet + opening panel**

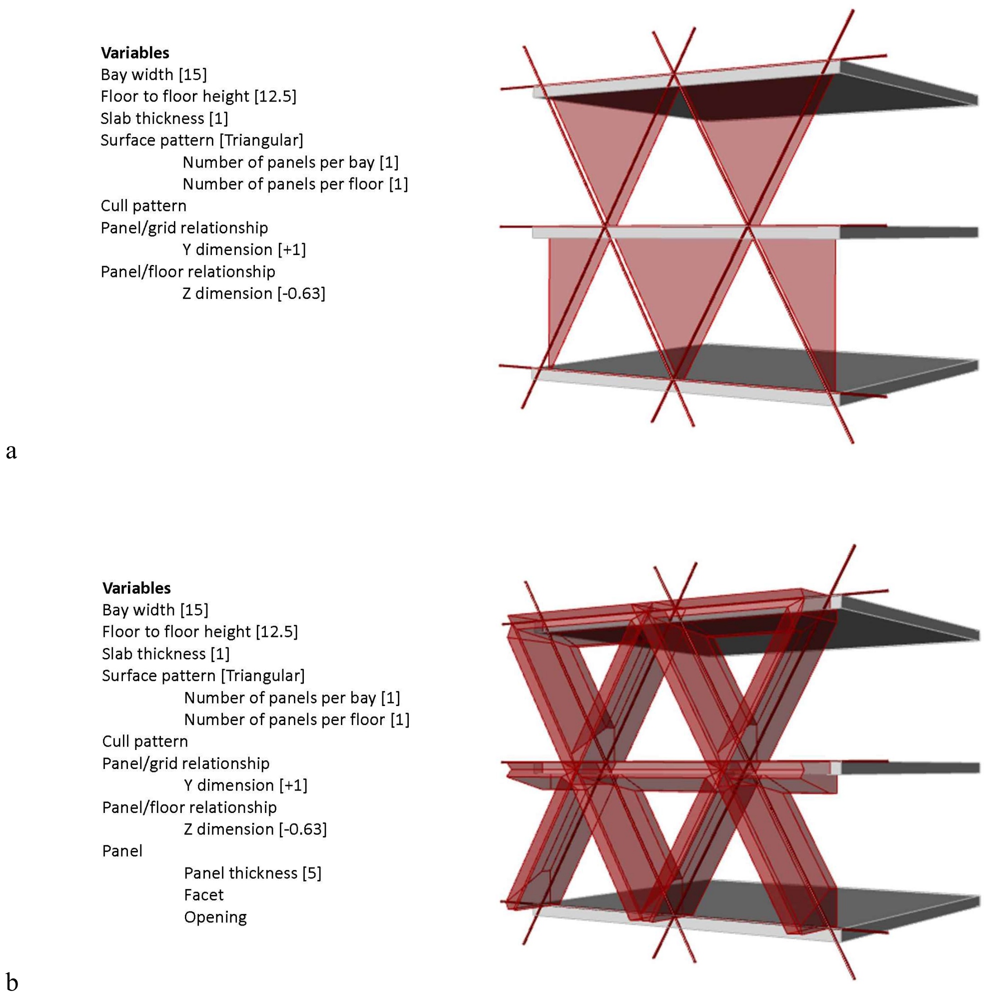



**Figure 127: Student Scheme 02 mapped scaffold – surface pattern (a) and panels (b)**

Figures 127a and 127b illustrate the typical precast map for Scheme 02. The relationship between the panels and the surface pattern is more complex than has previously been discussed or required. First, there is the use of a "cull" pattern to remove some of the triangular panel boundaries from the set; it is actually only every-other triangle that contains a panel. The remaining "open" panels are glazed. Second, the relationship between the surface patterns lines and the edge of panels is not consistent. Shown in Figure

128, the top of the panel is aligned with the horizontal lines of the pattern. However, the left and right sides of the panel are not. This "misalignment" is intentional and controlled; it provides geometry for node detailing.

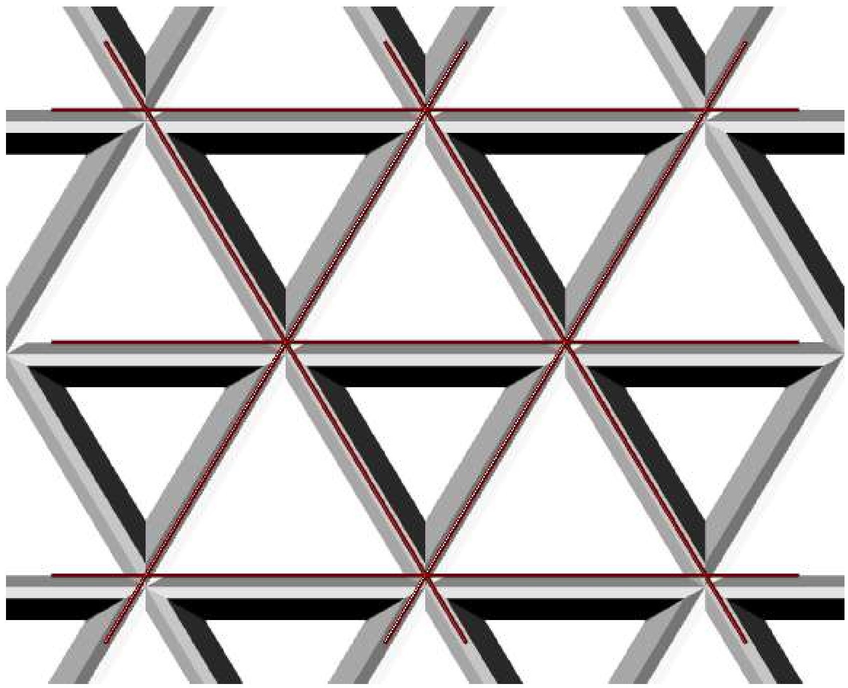


**Figure 128: Triangular panel façade alignment**

### *6.2.3 Design and detailing considerations*

With a more complex relationship between pattern and panel also comes a more complex set of data for coordination. Table 3 lists the data extracted from the scaffold model in Figure 125 for one panel boundary. Data used to customize the triangle facet + opening panel is shown in Table 4. Once these models are linked, additional previously described details can be applied. For example, because the panels for Scheme 02 are structural, a notch is required on the back side of the panel to support the floor slab.

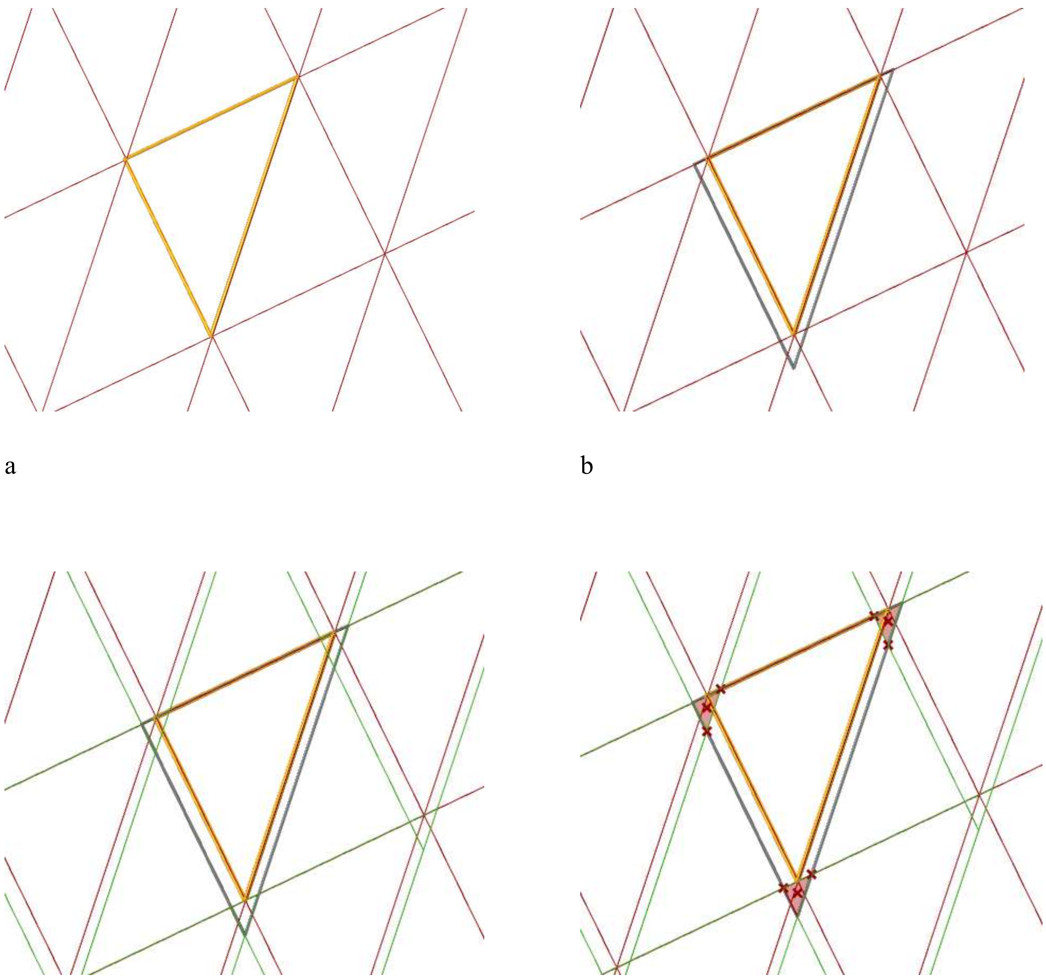
**Table 3: Example triangle facet + opening panel data (scaffold to panel)**

| Parameter | Dimension (in feet) |
|---|---|
| Panel label | 7 |
| Node 1 x coordinate | 67.500 |
| Node 1 y coordinate | -1.000 |
| Node 1 z coordinate | 40.500 |
| Node 2 x coordinate | 82.500 |
| Node 2 y coordinate | -1.000 |
| Node 2 z coordinate | 40.500 |
| Node 3 x coordinate | 75.000 |
| Node 3 y coordinate | -1.000 |
| Node 3 z coordinate | 28.000 |
| Panel boundary offset left | -0.917 |
| Panel boundary offset right | -0.917 |
| Panel boundary offset top | 0.000 |
| Panel nominal height | 12.500 |
| Panel nominal width | 15.000 |

**Table 4: Example triangle facet + opening panel data (panel to scaffold)**

| Parameter | Dimension (in feet) |
|---|---|
| Joint width left | 0.083 |
| Joint width right | 0.083 |
| Joint width top | 0.083 |
| Panel thickness | 5.000 |
| Facet offset left | 2.000 |
| Facet offset right | 2.000 |
| Facet offset top | 2.000 |
| Facet depth | 4.000 |
| Window offset left | 1.000 |
| Window offset right | 1.000 |
| Window offset top | 1.000 |

As mentioned, there is a relationship between the surface patterns lines, the edge of panels, and the node detailing. The simple panel boundary (Figure 129a) is offset by the dimensions defined in “panel boundary offset top,” “panel boundary offset left,” and “panel boundary offset right” in Table 5 (Figure 129b). This data is applied to all panel boundaries; green lines in Figure 129c. These lines delineate an area of overlap at the node (Figure 129d). When the center point of this area is connected to the intersection of the offset line (gray lines) and the application of this offset to adjacent panel boundaries (green lines), these new lines are used to “trim” the corners of the triangular panel.



a b c d

**Figure 129: Triangular panel boundary and node definition – panel boundary (a), offset boundary (b), applied to all panel boundaries (c), to define node (d)**

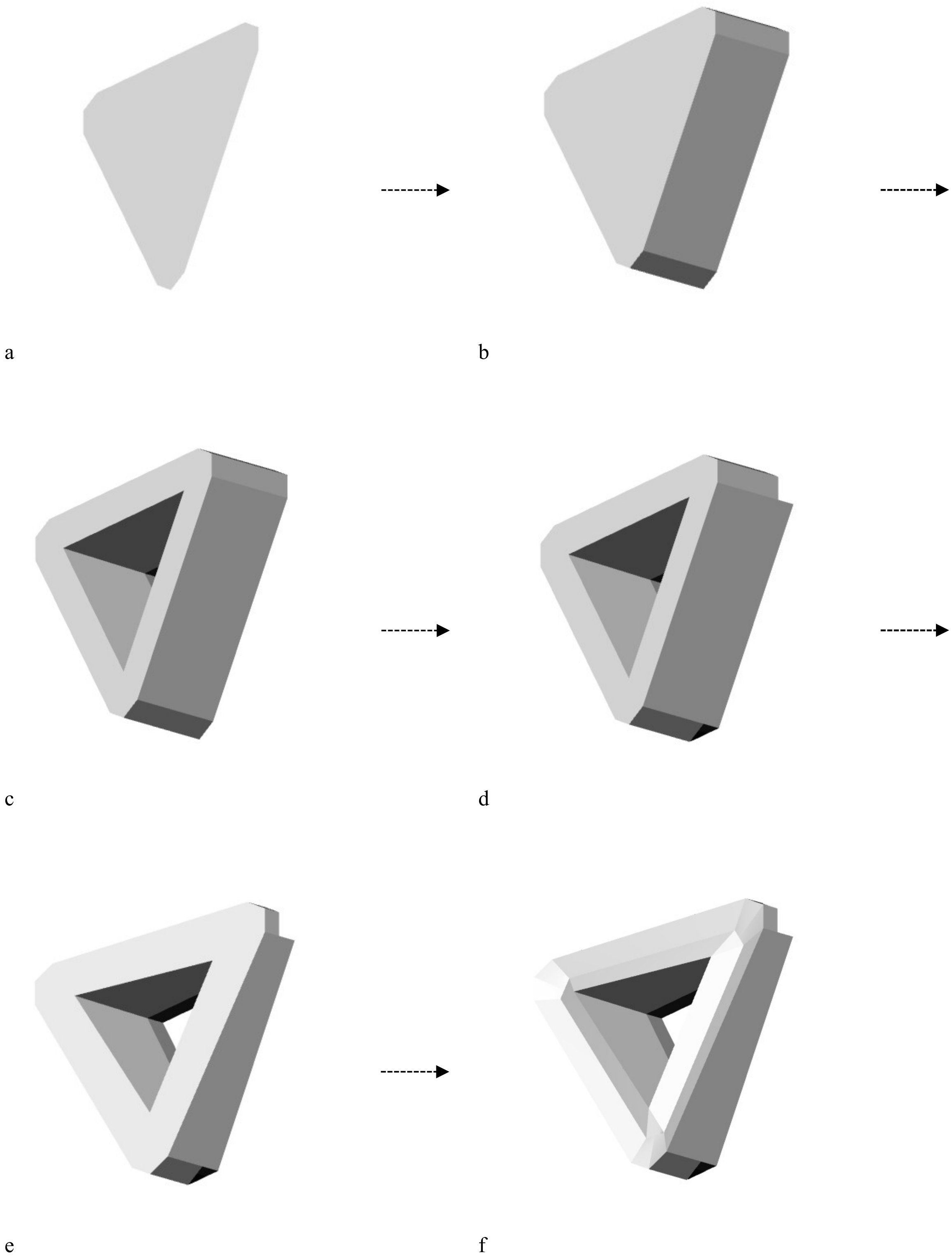



**Figure 130: Triangular panel family customization - panel boundary (a), thickness (b), facet and opening geometry (c), notch (d), taper (e), relief area (f.**

A predefined triangular facet + opening family model is applied to the edited panel boundary (Figure 130a). Data from Table 4 defines panel thickness (Figure 130b) as well as facet and opening geometry (Figure 130c). The panel can then be further edited with various features described in Section 4.3 that effect both the design and fabrication of the panel, such as notches to support the floor slabs (Figure 130d), tapering (Figure 130e), or relief areas (Figure 130f).

## 6.3 Scheme 03

### 6.3.1 Concept

**Figure 131: Student Scheme 03 rendering**

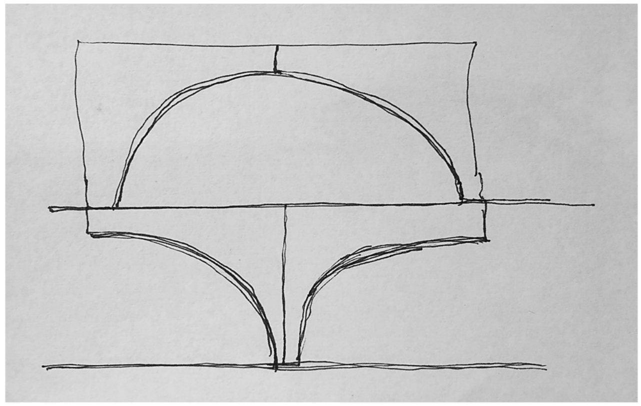


**Figure 132: Student Scheme 03 elevation sketch**

Regarding the design of their building, the student team for Scheme 03 noted:

> "The panels are the structural elements. Instead of using spandrels, the panels become arches and the double tees sit on them… We took inspiration from medieval stonework and arches. [The panels] frame… single rooms and provide balcony space on top of the panels."

### *6.3.2 Models*

Like Scheme 02, the panels for Scheme 03 serve as both enclosure and structure. A scaffold model (Figure 133) and panel frame (Figure 134) for the project are developed. Previous scaffolds have had consistent floor-to-floor height dimensions. The ground level of Scheme 02, however, is taller than the floor-to-floor height of the upper floors. This requires minimal changes to the original scaffold definition.

On the other hand, the “loft” panel is unlike those described in Section 4.3. Creating these kinds of panels requires a series of profiles, each of which are may be unique and may have different controlling variables. This makes defining geometrical generalities for model families difficult; while some flexibility in the geometry is possible, the panels are not nearly as flexible as other panels types with more clearly defined constraints. The surface pattern for the project, however, is a regular grid allowing the link between scaffold and defined panel to be relatively straightforward.

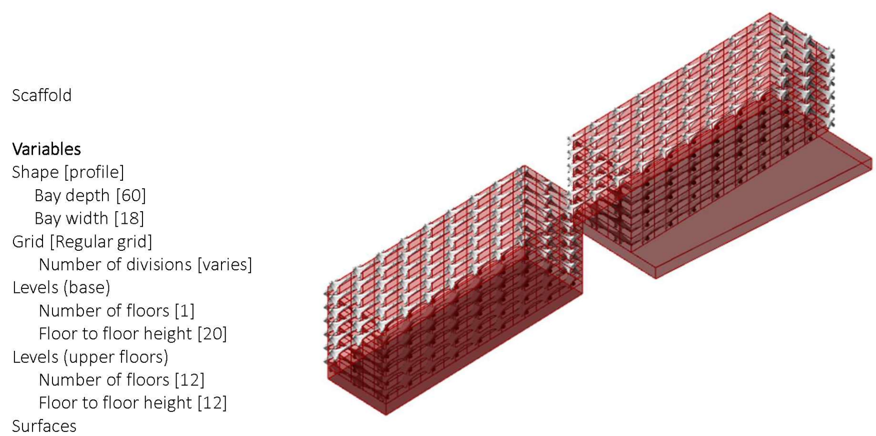



**Figure 133: Student Scheme 03 scaffold**

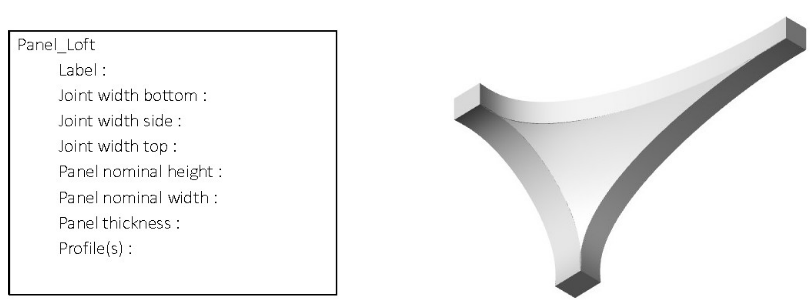



**Figure 134: Knowledge frame for lofted panel**

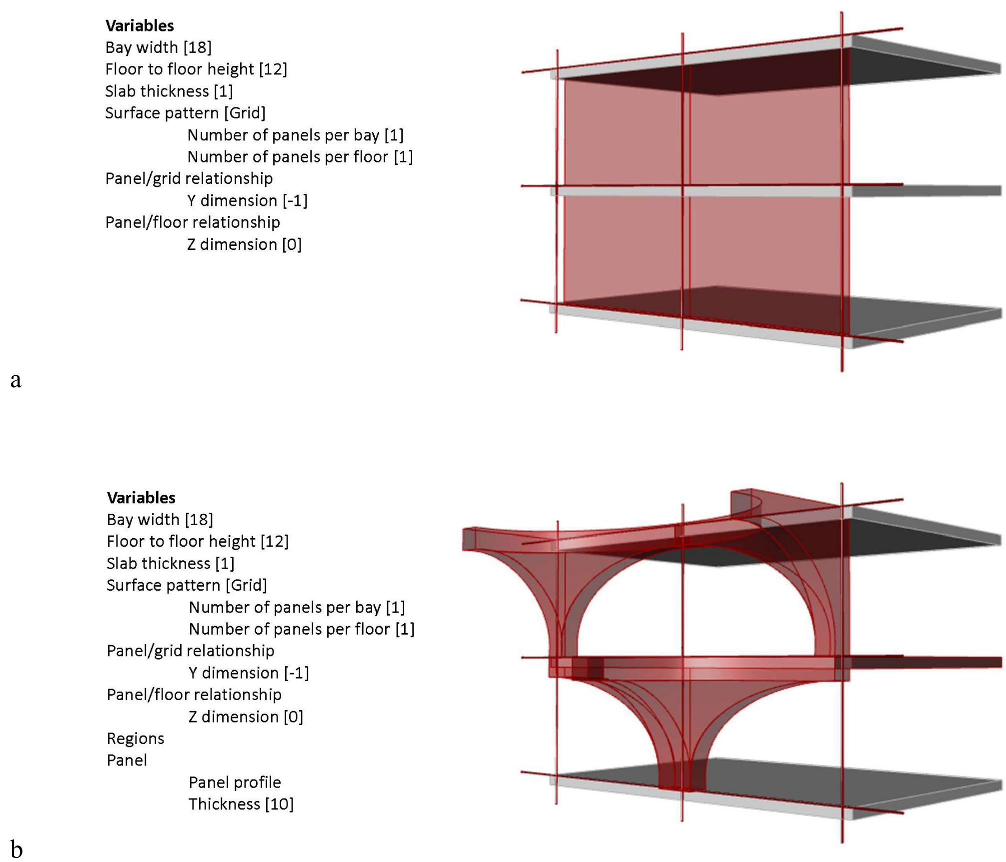



**Figure 135: Student Scheme 03 mapped scaffold – surface pattern (a) and panels (b)**

### *6.3.3 Design and detailing considerations*

Once the panel is defined, one of the areas that the team for Scheme 03 explored was the "aggregate" of panels, or how they are composed on the surface pattern. This occurred both to individual panels – flipping it horizontally or vertically – as well as across the building façade. Six panel options – created by mirroring and combining (e and f) the same lofted geometry – are shown in Figure 136.

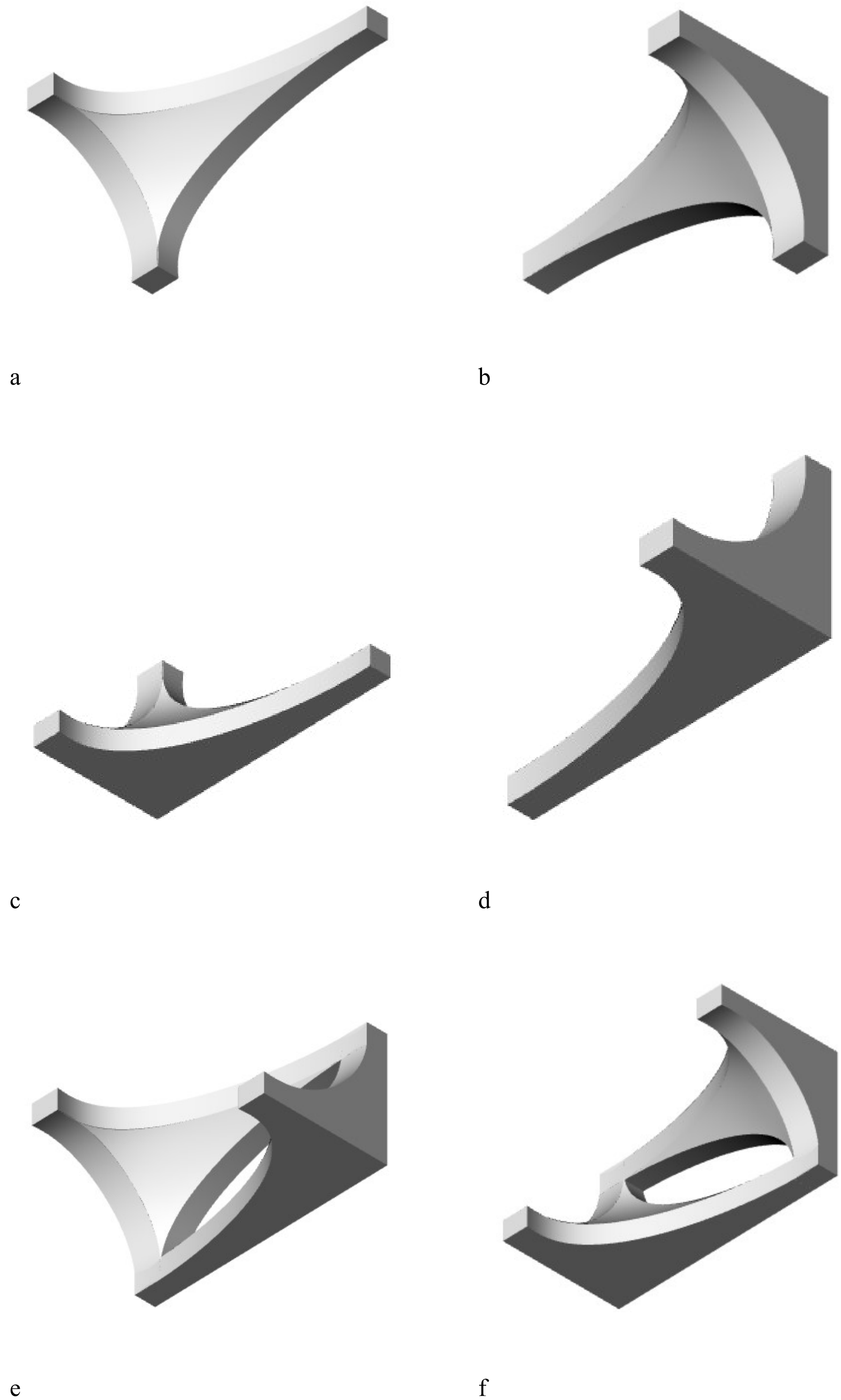



**Figure 136: Student Scheme 03 panel variations**

A model for exploring variations of applying panel variations to façade patterns is developed and depicted in Figures 135 and 138. First, each of the possible panel variations shown in Figure 136 is assigned a representative color and numerical value. Next, because the surface pattern is a regular grid, a spreadsheet (in this case using *Microsoft Excel*) can be used to "compose" the panel types in a pattern using each of the spreadsheet cells. Color coding the cells helps the user to arrange the pattern. However, it is actually the number that directs the program to place each panel type to the corresponding panel boundary in the model. The spreadsheet – and therefore the model – can be readily adjusted in any number of ways, exploring façade designs and "stonework" aggregation. (A term from the original student concept for the façade.) Individual panels can then be further detailed. Similar to Scheme 02, because the panels for Scheme 03 are structural, a notch can be added to the back side of the panels to support the floor slab. Further detailing may be desired or required based on the panel orientation or relationship between adjacent panel types. Additional considerations, such as panel weight and reduction techniques, could also be explored. (If solid concrete, at approximately 360 cubic feet and 150 pounds per cubic foot, the panel illustrated in Figure 136a would weigh 54,000 pounds or 27 tons.)

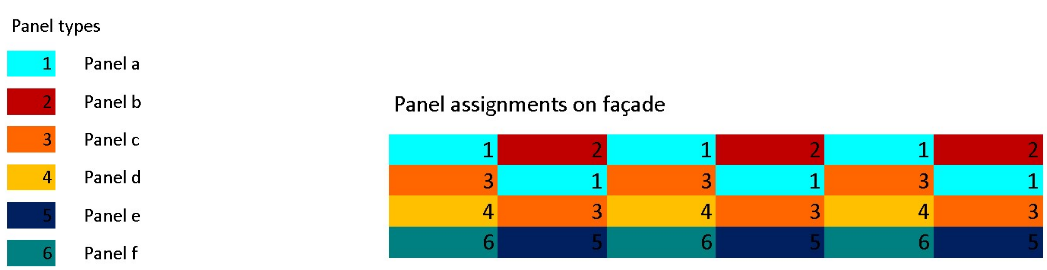



**Figure 137: Student Scheme 03 surface aggregate coding and composition**

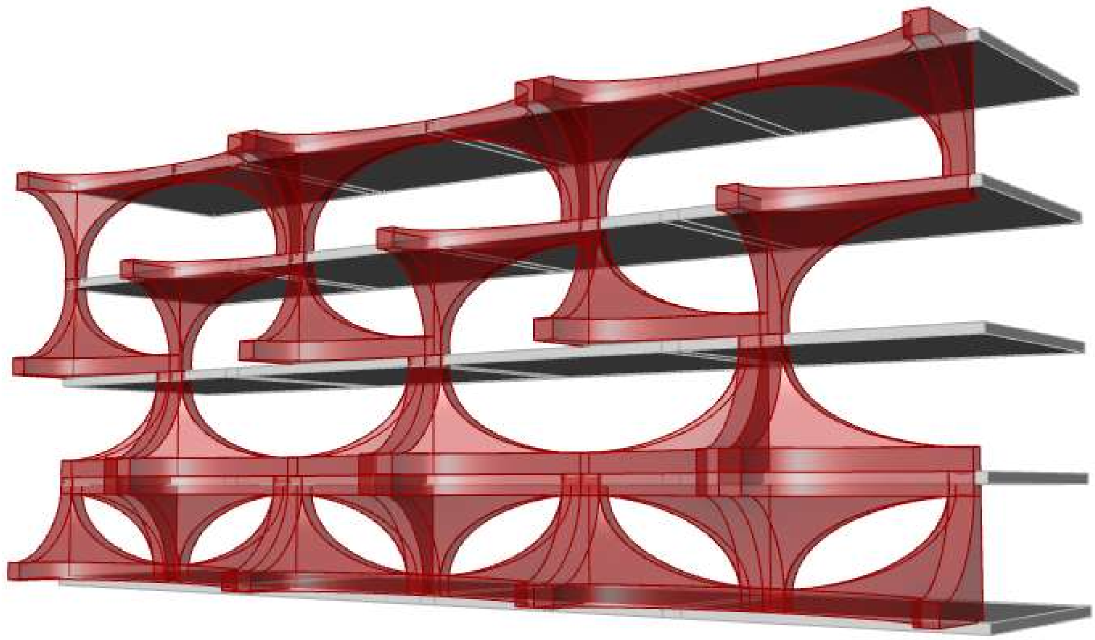


**Figure 138: Student Scheme 03 surface aggregate model**

# CHAPTER 7. CONCLUSION

This research has documented techniques for representing global and local digital models and described methods for linking and coordinating the currently disparate workflows of designers and fabricators of architectural precast concrete façades. The work aims to improve representations, enable conversations, and streamline exchanges. Research has documented, modelled, and referenced precedent buildings with architectural precast concrete façades in order to demonstrate the process of developing various parametric maps and their effect on design outcomes. It is the intent, however, for this work to allow new opportunities for precast buildings beyond those described. This chapter proposes a future state workflow that the described framework allows, reflects on the documented precedent buildings, models, and processes, and summarizes the contribution.

## 7.1 Future state

### *7.1.1 From exchange model to map*

A future state model based on the framework described herein is depicted in Figure 139. Taking the current state exchange model shown in Figure 6 as a starting point, a series of modifications are made. First, the boundaries between design and fabricator and the unidirectionality of exchanges are removed. This work has demonstrated that linked global and local models will enable more informed conversations between these project actors and, furthermore, that the flow of model data from one to the other is bidirectional and nonlinear.

Next, several of the diagram components are renamed as described in this work; Architectural Construction Model becomes Scaffold Model, the Design Development stage is redefined as Design Intent, Fabrication Model becomes Panel Model, and the Precast Detailing stage is relabeled Expert Knowledge. From the global perspective, Section 3.1 demonstrated how scaffold models can communicate a buildings' underlying structure. Their parametric qualities also allow scaffold models to act as behavioral models, going beyond mere "layout [of] precast elements" (what the Architectural Construction Model consists of) to a visual diagrammatic form (and potential variations) which represents a building schema in the designer's mind. Section 3.5 expanded on the distinction between design intent and design intention, which necessitates the change from Design Development (deliverable) to Design Intent (cognitive). From the local perspective, Section 4.3 demonstrated methods for embedding digital models with detailing features (such as those previously described in the Fabrication Model) in Panel Models. Section 4.4 then discussed the benefit of these models for coordination among designers and fabricators; rather than attempting to completely constrain panel models, the incorporation of such Expert Knowledge can enable conversations. In that regard, a further change in the future state diagram is that Architectural Review Model is removed and reconceptualized as the Map. The Design Intent Validation stage, renamed Map, is then moved to the center of the diagram. All components support map creation; this is not a linear process, rather it is iterative.

Design intent from the designer informs scaffold models. Expert knowledge from the fabricator informs panel models. Each of these can then be linked – in either direction as described in Sections 5.1.1 and 5.1.2 – and mapped. Furthermore, design intent may directly inform panel models and expert knowledge may directly affect scaffold models. (Hence the use of global and local as opposed to "top-down" and "bottom-up.")

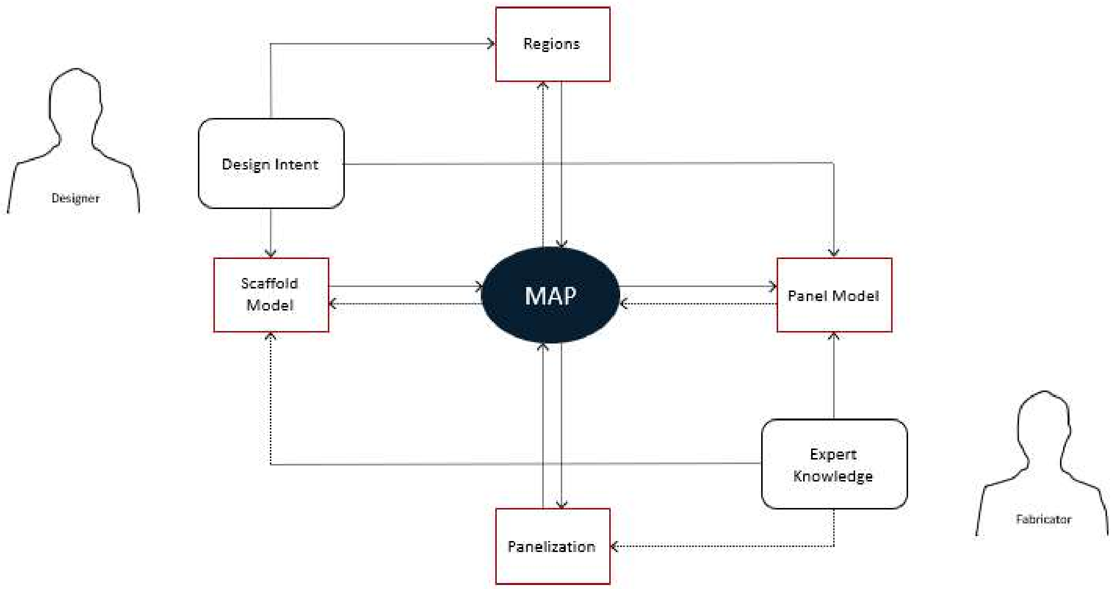



**Figure 139: Future state model – from exchange model to map**

Two additional concepts are added to the diagram: regions and panelization. Regions, described in Section 3.5, are a design tool, allowing various compositions of panel types, patterns, and/or materials to be arranged on building façades. Various models described herein have used the concept of regions at several different scales: façade organization for Suffolk University 20 Somerset Street (Figure 87a), precast distribution for 150 Rouse Boulevard (Figure 113), and panel types for Atlanta Public Library (Figure 105). Regions are related to but distinct from patterns. Patterns can define regions, or regions can be imposed on a surface without a pattern. A surface can be composed of one or multiple regions. Each region can be composed of subregions. Patterns can be applied to regions or subregions. Panels can be applied to regions, subregions, or patterns within regions or subregions. Regions can be used to identify certain panels – such as those at edges or corners or those interfacing with adjacent materials – that require specific detailing at the local level. The concept is powerful in controlling mapping as well as exploring façade designs.

Panelization, described in Section 5.2.1, is a phenomenon wherein the pattern perceived on a building façade does not necessarily dictate joints between individual precast pieces. (It is therefore difficult to define which precedent buildings adopt direct or indirect mapping.) For some buildings, the pattern and panelization may align. For others, such as demonstrated for Roundhouse (Figure 100), precasters may suggest joining adjacent panels together in order to cast larger precast pieces. Or, the size of panels illustrated in design documents may need to be revised as was discussed in Student Scheme 01 (Figure 121). Panelization is therefore another powerful tool for controlling mapping and fabrication issues. Regions are informed by design intent and panelization is informed by expert knowledge. Each of these also has a recursive relationship to the map; it is this map that informs global and local project coordination.

### *7.1.2 From DSSBF to coordination model*

Looking again at the DSSBF diagram shown in Figure 7, similarities can be seen in this process. As a framework for coordination, this research has sought to connect both cognitive and tangible project descriptions in a similar way that the DSSBF model connects SBF and drawings. In DSSBF, "shapes and spatial relations are an intermediate abstraction

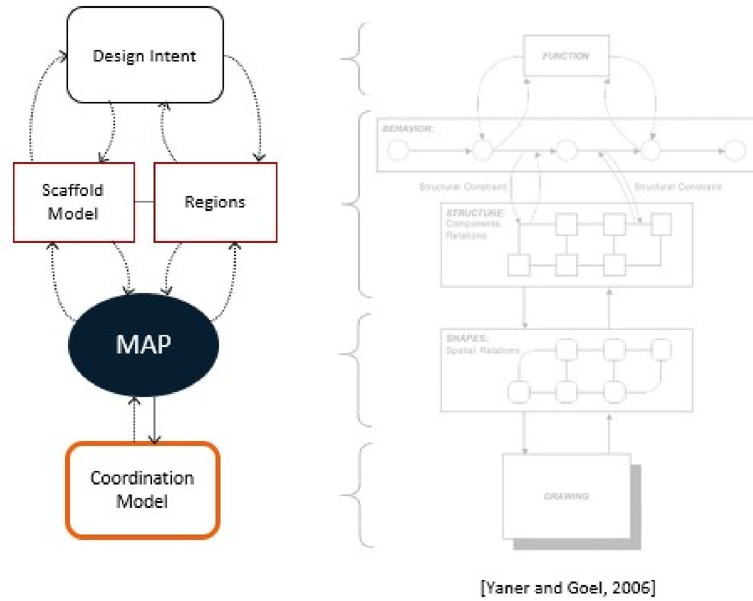



**Figure 140: DSSBF for design intent**

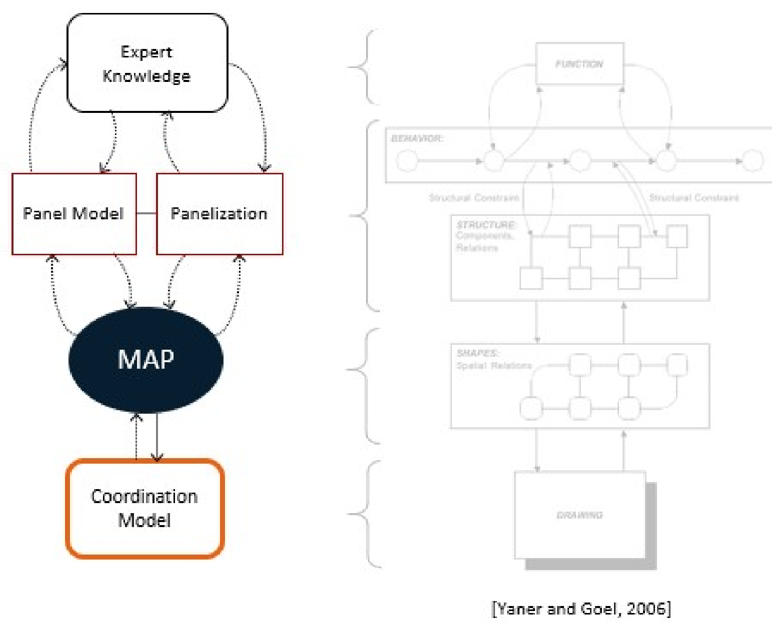



**Figure 141: DSSBF for expert knowledge**

between the structure and the drawing." [Yaner and Goel, 2006] Components from the process map in Figure 139 are rearranged to mimic the format of the DSSBF model; illustrated in Figures 140 and 141. This research has defined components and parameters from both designer and fabricator perspectives; for both design intent and expert knowledge. In this diagram, "drawing" is reconceived as "coordination model." It is assumed that a coordination model is a digital extension of the drawing concept that the original DSSBF model is referencing. Therefore, from the designer point of view, maps are the intermediate abstraction between SBF (design intent, scaffold model and regions) and the coordination model. And, from the fabricator point of view, maps are the intermediate abstraction between SBF (expert knowledge, panel model and panelization) and the coordination model. It is when these maps are aligned that coordination occurs, diagrammed in Figure 142. Herein, design models can propagate directly to for-construction models.

As with the model shown in Figure 139, design intent is also linked to panel models and expert knowledge to scaffold models in Figure 142. To complete the cycle, the coordination model also loops back to inform design intent and expert knowledge; designers and fabricators learn from previous experience and bring that to future projects. This is the kind of coordination through distributed cognition that customizable models (both through instances and through editing to create new families) aims to achieve. Furthermore, implementation of this framework aspires to overcome a major issue in the typical Design-Bid-Build project; lack of trust. This is a contributing factor in the disconnect between designer and fabricator modes of working and depicting projects. This disconnect was caused by or reinforced by contractual obligation, though the root cause may be a matter of interpretation of intent and representation. As such, this work does not necessarily replace any actor or fully automate any process, rather it enables coordination among them. Through conversation and streamlined exchanges of digital models at global and local scales, the work also aims to significantly reduce – or eliminate – the need for remodeling.

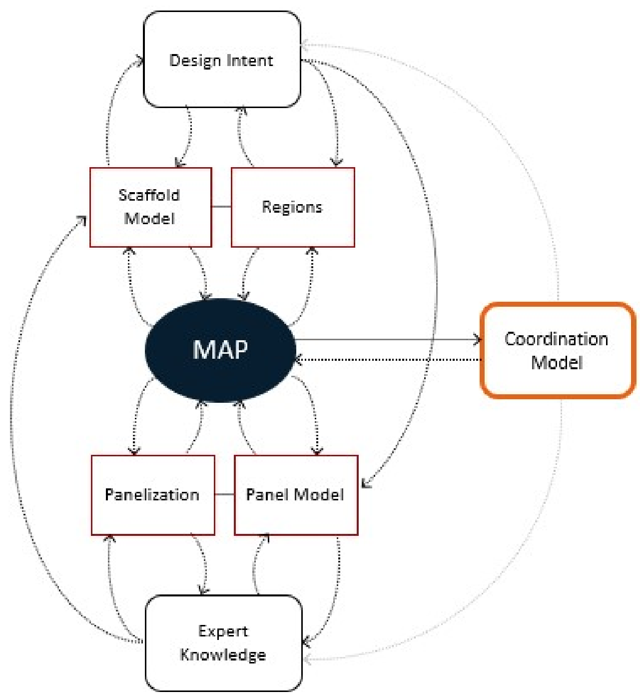



**Figure 142: Future state model – from DSSBF to coordination model**

### 7.1.3 Mapping assumptions and protocols

This research has focused on establishing a framework for coordination using current, prevalent software. User testing of this framework and development of new software specifications is outside of the current scope. Issues related to concrete mix and performance, formwork construction, panel site installation, and structural anchoring could also be included in future work. Forthcoming work could additionally consider material possibilities of precast, supplementing model geometry with data based on, for example, structural performance, mix design, alternate systems (such as GFRC), production methods, formwork construction, accessories (such as embeds, rebar, lifting hooks, and more), knowledge regarding transportation, and more. The described framework aims to enable conversations between designers and fabricators to address as many of these issues as possible – through digital models – early in the design process so that more ambitious designs for precast are possible. Through this process, tensions between these actors – caused by miscoordination, exaggerated by disparate workflows, and resulting in lack of trust – can be resolved. Protocols for developing surface patterns, panels, and maps establish a baseline for coordination of architectural precast concrete façades which can lead to both further detail development and design exploration.

Assumptions for developing the mapping strategies described in this work include:

- The list of precedent buildings in Table 1 include all possibilities and varieties of architectural precast concrete façades
- Building masses generally conform to the described scaffold model, defined by shape, grid, levels, and surfaces

- Façades surfaces are either flat, ruled, or developable
- Façades surfaces are panelized
- Either the building superstructure (consisting of columns and slabs) is available to carry the load of façade panels or the panels are structural (capable of carrying the load of themselves and some portion of building slabs)

In order for designers and fabricators to effectively implement the modelling, mapping, and coordination strategies described herein, a list of questions and corresponding protocols is developed for use in advancing the generalized "meta-model" illustrated in Figure 142 for implementation for specific projects; Table 5.

**Table 5: Mapping questions and protocols**

**Defining surface patterns**

*After isolation of individual surface:*

| | | |
|---|---|---|
| Does any surface geometry align with scaffold model? | If yes; link to those variables. | |
| | If not, is the intention to be separate? | |
| | | If yes; create new variables. |
| | | If no; define relationship algorithm. |

| | |
|---|---|
| What is the main surface pattern? | Options and variables are discussed in Section 3.3; assign to surface. |
| What operations occur within this surface pattern? | Examples include regions or random reduce of panels; assign to surface. |
| Are there embedded regions and patterns to define? | If yes; assign to surface. |
| | Are there further operations within each of these regions or panels? |
| | If yes; assign to surface. Repeat as necessary. |

*Isolate individual panel boundaries as discussed in Section 5.1.1.*

**Defining panels**

*For each panel family:*

| | |
|---|---|
| What is the initial panel type? | Options include flat, non-rectangular. Create basic panel and define parameters. |
| What are main panel features? | Options and variables are discussed in Section 4.3; define features and parameters. |
| | What are secondary panel features? |
| | Define features and parameters. Repeat as necessary. |

| | |
|---|---|
| Is control of features combined or separate? | If combined, define relationship algorithm. |
| | If separate, is that the intention? |
| | If yes; continue. |
| | If no; define relationship algorithm. |
| Is panel geometry and certain features effected by location? | Effected features may be based on: |
| | Relationship to and position in scaffold (middle, edge, corner, etc.) |
| | Relationship to adjacent panels |
| | Relationship to adjacent materials |

*Represent panel feature data as described in Section 5.1.2.*

**Defining mapping**

*Given panel boundaries and panel feature data:*

| | |
|---|---|
| What is the relationship between pattern and panelization? | See Section 5.2.1 and Appendix H. |
| | Individual panels can then be customized per "defining panels" above. |
| Do any surface patterns cross panel joints? | See Section 5.2.2 and Appendix I. |

| | |
|---|---|
| | Individual panels can then be customized per "defining panels" above. |
| Are there any other mapping considerations? | |

*Link individual panel boundary and panel data as described in Chapter 5.*

**<u>Other questions for coordination</u>**

*Given mapped surface and panels:*

| | |
|---|---|
| What is the relationship between surface and scaffold model? | See Section 3.2. |
| What is the relationship between panel and building structure? | See Section 3.2. |
| Are there any other coordination considerations? | |

*Modify surface patterns and/or panels as necessary. Iterate.*

## 7.2 Reflection

One goal of this research has been to explore and link a variety of designs for architectural façades. Considering the list of precedent buildings with architectural precast concrete façades listed in Table 1, there are four categories into which each of these buildings can be placed:

1. Referenced in this work and easily represented within the described framework (53)
2. Not referenced but equivalent to a referenced example (27)
3. Would require minor adjustments to demonstrated modelling and/or mapping techniques (20)
4. Not possible to represent within the described framework (0)

For each of these categories, the number of buildings that fall into each are indicated in parentheses above. For the one hundred buildings (Shands is omitted in this count because of its brick facing but is included in the list because of the author's relevant experience with the project), fifty-three are referenced in this work and easily represented within the described framework and twenty-seven are not referenced but equivalent to a referenced example. Consequently, eighty of the listed buildings are easily represented within the described framework. It is further suggested that all of the buildings are able to be represented (none of them are not possible to be represented). For the remaining twenty buildings, minor adjustments to demonstrated modelling and/or mapping techniques would be necessary in order for them to take advantage of described framework. For these twenty buildings, the reason(s) predicating adjustments include:

- Additional panel features, such as those required for Pierresvives by Zaha Hadid Architects (panel curved in section), Dior Miami Façade by Barbaritobancel Architectes (panel curved in plan), U.S. Embassy Dublin by John M Johansen (lofted panel), The Broad Museum by Diller Scofidio + Renfro (lofted opening), CBR building by Constantin Brodzki and Marcel Lambrichs (lofted panel and opening), Eurocenter by Ten Arquitectos (fins), Tour Towers by Barkow

Leibinger (twist), or Florida International University Science Classroom by Perkins + Will (tapering in multiple directions).

- Complex panel feature coordination as needed for Colorado Center by Tryba Architects, Indiana University Stadium North End Zone Addition by Ratio Design, and King Abdullah Academy by Bowie Gridley Architects.
- Alternate or complex scaffolds or mapping procedures as seen in Italy Pavilion for the Milan Expo by Nemesi Studio and Textilmacher by tillicharchitektur.
- Novel construction systems, as in the case of Frank Lloyd Wright's Textile Block Houses – Ennis (Ennis-Brown) Residence, Freeman Residence, Millard Residence (La Miniatura), and Storer Residence.
- Issues of fabrication, as with Brown Deer School Field House by Plunkett Raysich Architects (defining and coordinating pattern of pigmented concrete), MuCEM by Rudy Ricciotti (coordinating complex perforation pattern, thin panels with steel support structure), Perot Museum of Nature and Science by Morphosis (reuse of formwork to save costs while keeping appearance of unique panels across façade).

Regarding the list of fabricator coordination items discussed in Section 4.4;

- Dimensions of joints between panels are controlled via panel model; the "joint width" dimension between the panel boundary and geometry of the panel itself;
- Dimensions of joints between panels and structure are controlled via scaffold model; the "offset surface dim" between the structural grid and the surface onto which the panels are placed;

- Dimensions and weight of panels can be readily collected and additional routines can be implemented based on this data;
- And additional features such as “drafts,” “flares,” “miters,” or customization of various other profiles is possible.

The quality and merit of this research may be evaluated by the number of projects that the described framework is able to represent and the flexibility of described models to exhibit design exploration and fabricator coordination. Future work – still within this framework – could describe and include additional panel features. Panels curved in section or plan would simply require a revised panel profile, as did the triangular panel for Student Scheme 02. The same is true for “fin” panels and “twist” panels (both of which could be based on the panel developed for Student Scheme 01, Figure 118). And, as was previously mentioned in Section 4.3.9, future work could allow panel tapering in multiple directions.

More complex features that could also be explored are those that include curved or lofted forms. Briefly described for Student Scheme 03, creating curves or lofts requires a more complex set of controlling variables, making defining geometrical generalities for model families a challenge; so much so that lofted panel families may only be useful for generating variations for one building. This situation is not unique to curved panels; the same could be said for the IBM Boca Raton panel shown in Figure 11. The panel geometry becomes so complex and constrained that it is only useful for that building. In fact, that panel family, rather than being named a concateny of features (i.e. negative facet + opening + rib + positive facet, etc.) may instead be referred to as “Boca panel.”

This approach to panel variation within a "language" for a specific building starts to address another important issue in precast that has not yet been discussed: economy achieved through repetition of panels and reuse of formwork. According to the PCI Design Handbook, "to fully realize… benefits and thereby gain the most economical and effective use of [precast]," one of the principles that should be used is "maximum repetition." [Precast/Prestressed Concrete Institute, 1999] The vast majority of the buildings listed in Table 1 employ repetition. However, there are a few – such as 150 Rouse Boulevard, Burntwood School, Dior Miami Façade, Italy Pavilion for the Milan Expo, Perot Museum of Nature and Science, and Tour Towers – wherein the design suggests that all panels are unique. Further analyses of these buildings could reveal another layer of surface pattern and coordination, that of reused panels. Similar to the modelling methods used for Student Scheme 03, variations of panel types can be arranged across the façade in seemingly random patterns. Not only would this approach save time on creating the digital model, but could provide a map for locating matching panels or portions of panel geometry and therefore the opportunity for fabricators to reuse formwork and save project costs.

Beyond the categories of "direct" and "indirect," this dissertation described two example precast mapping types: panelization and patterns across panels. Protocols for developing such maps, like scaffold and panel models, are intended to provide framework for customization. It is not proposed that a given project uses one of these types exclusively. Rather, a variety of mapping methods could be used iteratively during the design process to coordinate among various scaffold and panel models and between project actors. Alternate map types may include special considerations for GFRC panels, maps for reinforcing bars (or other systems such as employed in the Textile Block Houses), maps limiting sizes of panels based on weight or other measures, incorporation of insulation, mechanical or other building systems, modelling of complex formwork construction, and more.

This research has proposed a disruption to the current state of design and construction processes, suggesting that the current workflow is broken. Yet, solutions exist; great precast buildings have been built. The first stage in expanding successes is implementing the new framework for coordination among project actors; applying and making more effective use of digital models. New contract types and project delivery methods will need to take shape. Therein, mapping of global and local descriptions may vary in schedule and scope per project, for example:

- Designers may begin the Concept Phase of work by creating parametric massing models, increasing complexity and level of detail over time to include façade studies. Such models may or may not be shared with fabricators upon engagement.
- Fabricators may create parametric scaffold models based on information received from the design team at the end of Construction Documents. This scaffold can be used to place and associate instances of parametric panel family models. Customized panels models may or may not be shared with designers in lieu of shop drawings.
- Designers and fabricators may separately develop digital models and, at the beginning of Design Development, map these descriptions to one another using the described protocols. Steps can then be taken to reconcile discrepancies.

In this regard, creation of the map may take place at various or recurring stages and can be implemented by any stakeholder; many more possibilities exist than the example scenarios described above. In whatever application, mapping elucidates, explicitly associates, and clarifies representations, not only of digital models but also within the minds of designers and fabricators. Furthermore, mapping strategies could be executed in an even broader sense, before material selection. This research has focused on architectural precast concrete façades in order to show the potential of the proposed framework. However, parametric digital models could be similarly used to explore a variety or combination of different materials, disclosing the results in façade panelization, and capitalizing on the ability to coordinate with building scaffold and structure. Extensions could also track the effect of design decisions and material specification on project costs.

## 7.3 Contribution

This research has addressed the question: How can data from parametric models representing global and local descriptions of architectural precast concrete façades be linked in order to bridge the currently disparate workflows and values of designers and fabricators, simultaneously enabling design exploration and incorporating fabrication details, during concept phases of work? While these issues are not isolated to a specific aspect of built work, in order to show the potential of the concept, research is presently focused on a particular system; architectural precast concrete façades. Existing precedent buildings with architectural precast concrete façades were referenced to demonstrate the process of developing various parametric models at multiple scales. Expert knowledge from fabricators regarding panel geometry and assembly details was codified and used to increase functionality of the models.

In the initial problem statement of this research, the disconnect between designer and fabricator modes of working and depicting projects is described as partly due to standard contractual procedures. It can be further argued that this separation has been exaggerated by industry-focused software which align with goals for certain project actors; designer exploration and fabricator specification. While aiming to link digital models from both global and local perspectives, this work has also – purposefully – used software with which project actors are already accustomed. Global descriptions in Chapter 3 were developed using *Grasshopper*, a visual scripting plug-in for *Rhinoceros*, a software popular among architectural designers for its abstract, quick, and precise modelling capabilities. Local descriptions in Chapter 4 were modelled in *Revit*. *Revit* is a component-based software well-suited for the production of construction documents and project coordination. By explicitly defining specific data required for translating back and forth between global and local descriptions, this work has also defined methods for translating models between disparate software interfaces. By referencing current software, this work can be readily employed. It should be noted, though, that the use of specific or distinct modelling software is not required. Indeed, local descriptions could be defined in *Grasshopper* and global descriptions in *Revit,* or both using the same (or some other) program and coordination perhaps even occurring virtually and recurrently. What is critical is geometrical control of each representation and the map that links them together. Such control could be established by one or more "owners" of geometry and maps between one or more (current or evolving) software platforms.

Chapter 3 described several interrelated methods of precisely defining geometry: scaffolds, surface patterns, and regions. Scaffold models describe parametric relationships between key building systems (shape, grid, levels, and surfaces). These can be customized for specific instances and adapted to many different scenarios. Scaffold models represent a three-dimensional diagram of a building structure. Made explicit, the concept is inherent to building design and construction organization, using building column grids and dimensions of floor slabs to locate additional elements. The ability to model such a scaffold parametrically allows for flexibility for both design and coordination purposes. Extending to the other geometrical definitions – as shown through examples in Chapter 5 – scaffolds define the location and extent of surfaces onto which surface patterns and regions can be applied. Surface patterns (which describe parametric panel boundaries) and regions (defined portions of surfaces) have a recursive relationship. Surface patterns can be used to define regions and surface patterns can be applied to regions. The goal of defining surface patterns and regions in this work is to describe the extent of panel boundaries. This data is used to map from scaffolds to panels or from panels to scaffolds. That is, scaffolds can define the boundary to which a panel is applied (see example in Figure 88) or panels can derive the bounding box to which a scaffold is associated (see example in Figure 98). Parameters that control scaffolds can also define aspects of surface patterns or regions. This would result in a façade that expresses buildings' structural logic. Alternatively, surface patterns and regions can be controlled independent of scaffold variables, resulting in a "curtain wall" façade that is indifferent to the buildings' structural logic. The described modelling and mapping techniques offers the opportunity to explore and coordinate unconventional designs that may have otherwise been avoided. This notion relates back to Atterbury's vision for precast housing; brining good design to the masses. This research suggests that informed and intentional use of digital models permits the same.

Design Assist, implemented as described for Perot Museum, is a project delivery method that acknowledges the importance and benefits of designer and fabrication conversation regarding design intentions and expert knowledge during the design process. The framework for creating and linking digital models of global and local descriptions of architectural precast concrete façades described in this work offers the possibility of further enhancing such conversations through shared models and workflows. Indeed, this framework extends beyond coordination to systematically embed design intent models with fabrication knowledge that allows them to mature directly into models for construction and expedite much of the back and forth of traditional work flows.

Section 1.3 discussed three previous examples of work seeking to capture precast concrete models and workflows. These systems may be characterized as focused on standardized elements (*Architecture in Precast Concrete*), automated detailing (*Edge for Revit*), and regulated exchanges (*Information Delivery Manual for Precast Concrete*). Alternatively, this research has promoted a framework that is generalized, flexible, and customizable. The basis for this argument is that having conversations – sharing intentions, and clarifying knowledge – is just as important to project coordination as the creation of project representations. Furthermore, these conversations can be aided by parametric models that are customizable rather than standard or automated and processes that exchange data directly but with purpose rather than regulation. When embraced by clients and design and construction teams, the proposed disruptions to current workflows will necessitate changes to traditional contracts and procedures regarding shared creation and use of digital models.

There are three main benefits that this research has endeavored to address: increased design agency, reduced remodeling, and enabled additional routines. The defined framework and parametric models – of scaffolds, surface patterns (including regions and panelization), and panels – facilitate a wide variety of precast design exploration, far beyond even the examples discussed. Having these models accessible, in fact, will enable not just coordination but design control. The earlier in the design process coordination occurs, the more likely projects teams will be able to avoid value engineering and curb redesign time or being stuck with undesirable building features. [Light, 2009] Furthermore, these coordinated models can propagate directly to for-construction models and serve as more accurate representations for additional routines such as daylight and shadow studies, energy and building performance simulation, and automated detailing. This direct exchange eliminates the need for the current time-consuming and error-prone remodelling of architectural components and may even cause the current shop drawing submittal review process loop to become obsolete. It is the intent of this research to provide both designers and fabricators a series of roadmaps for coordination. Strategies for achieving such coordinated models have been demonstrated through:

- Documented future state framework for coordination process diagrams (Figures 138 and 141)
- Defined parametric models at both global level (Chapter 3 and Appendix B) and local level (Chapter 4 and Appendix E)
- Described methods for linking global and local digital models (Chapter 5 and Appendixes F, G, H, and I)

- List of protocols for creating and linking customized models for coordination (Section 7.1.3)

In addition to precedent buildings, these strategies have been implemented through digital modelling and exploration of design and fabrication issues for three student projects (Chapter 6). These examples postulate the effects of this process on emergent design and fabrication coordination. Future work will extend this research to include additional precast panel features and surface patterns, alternative mapping approaches, as well as other panelized (or other systems of) exterior façade cladding. It has been shown that linked digital models can stimulate interaction between designers and fabricators – bridging currently disparate workflows and value systems – while simultaneously enabling design exploration and incorporating fabrication details. This work further aspires, thereby, to make design intentions explicit, documented, and analyzed – permitting novel theories for contemporary architectural practice to emerge.

# APPENDIX A. FURTHER INFORMATION ON PRECEDENT BUILDINGS WITH ARCHITECTURAL PRECAST CONCRETE FAÇADES

Information on each of the precedent buildings listed in Table 1, including key issues, surface patterns, panels types, and references is shown on the following pages.

# 1200 Intrepid

## Bjarke Ingels Group
## Philadelphia, Pennsylvania, 2016

Image downloaded from
http://www.big.dk/#projects-navy in June 2018.

Key Issues
Double curved facade
Structural steel system embedded into the precast concrete panels

Surface pattern
Vertical running bond

Panel type(s)
Flat – hung at angle

References

http://www.big.dk/#projects-navy

https://www.archdaily.com/799118/1200-intrepid-bjarke-ingels-group

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=1200-intrepid

# 150 Rouse Boulevard

Digsau
Philadelphia, Pennsylvania, 2012

Image downloaded from
http://www.digsau.com/projects/150-rouse in June 2018.

Key Issues
Multiple textures create a large-scale pattern over the pattern of construction joints

Surface pattern
Regular grid, Irregular grid

Panel type(s)
Opening, Relief pattern

References

http://www.digsau.com/projects/150-rouse

# 250 High
NBBJ
Columbus, Ohio, 2015

Image downloaded from http://www.nbbj.com/work/250-high/#next in June 2018.

Key Issues
Panels flush with edge of slab

Surface pattern
Staggered quads horizontal

Panel type(s)
Flat

References

http://www.nbbj.com/work/250-high/#next

# 4260 Cortex

## Cannon Design
## St. Louis, Montana, 2016

Image downloaded from https://www.cannondesign.com/news-insights/news-item/4260-cortex-wins-2018-pci-award/ in June 2018.

Key Issues
Irregular panelization

Surface pattern
Custom quads

Panel type(s)
Flat (openings are in between panels)

References

https://www.tarltoncorp.com/project/4260-forest-park-avenue/

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=4260-cortex

https://www.cannondesign.com/news-insights/news-item/4260-cortex-wins-2018-pci-award/

# 84.51° Centre

## Gensler
## Cincinnati, Ohio, 2016

Image downloaded from https://www.gensler.com/projects/84-51-centre-1 in June 2018.

Key Issues
Interior connections exposed to view

Surface pattern
Horizontal random quads

Panel type(s)
Openings (to create “L” and “C” shape panels), Relief area

References

https://architizer.com/projects/8451-centre/

https://www.gensler.com/projects/84-51-centre-1

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=5th-race-street-development

# 900 North Glebe Road

Cooper Carry
Arlington, Virginia, 2011

Image downloaded from http://www.coopercarry.com/project/900-north-glebe/ in June 2018.

Key Issues
Punched precast expression to relate to residential facing facades

Surface pattern
Regular grid

Panel type(s)
Opening, Reveal, Relief area (positive and negative)

References

http://www.coopercarry.com/project/900-north-glebe/

# Airea
## VIDARQ
## Mexico City, Mexico, 2007

Image downloaded from http://www.coopercarry.com/project/adtran-corporate-headquarters/ in June 2018.

Key Issues
Regions

Surface pattern
Irregular grid

Panel type(s)
Flat

References

http://www.coopercarry.com/project/adtran-corporate-headquarters/

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=adtran-corporate-headquarters

# Adtran Corporate Headquarters

Cooper Carry
Huntsville, Alabama, 2000

Image downloaded from
http://www.vidarq.com/h_airea.html in June 2018.

Key Issues
Radiused corners

Surface pattern
Regular grid

Panel type(s)
Opening, Relief area

References

http://www.vidarq.com/h_airea.html

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=airea

# American Pharmacists Association Headquarters

## Hartman-Cox Architects
## Washington, D.C., 2009

Image downloaded from https://www.hartmancox.com/american-pharmacists-association-headquarters in June 2018.

Key Issues
High level of detail

Surface pattern
Irregular grid

Panel type(s)
Reveal, Relief area, Relief pattern (negative)

References

https://www.hartmancox.com/american-pharmacists-association-headquarters

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=american-pharmacists-association-headquarters

# Armstrong Rubber Company Headquarters

## Marcel Breuer and Robert F. Gatje

## West Haven, Connecticut, 1970


Image from Hyman I. *Marcel Breuer, Architect: The career and the buildings*. Harry N Abrams Inc Publishers. 2001.

Key Issues
Structure hung from steel trusses at roof

Surface pattern
Regular grid, Vertical running bond (by region)

Panel type(s)
Opening, Reveal, Facet, Gesture

References

Hyman I. *Marcel Breuer, Architect: The career and the buildings.*

http://breuer.syr.edu/

# Atlanta Central Public Library

## Marcel Breuer and Hamilton P. Smith and Stevens and Wilkinson
## Atlanta, Georgia, 1980

Image downloaded from https://archpaper.com/2016/07/marcel-breuer-central-library-atlanta-saved/ in June 2018.

Key Issues
Special shapes including corners

Surface pattern
Running bond horizontal, Irregular grid

Panel type(s)
Flat, Reveal, Corner

References

Hyman I. *Marcel Breuer, Architect: The career and the buildings.*

http://breuer.syr.edu/

https://archpaper.com/2016/07/marcel-breuer-central-library-atlanta-saved/

# Bank Lambert

## Gordon Bunshaft (SOM)
## Brussels, Belgium, 1965

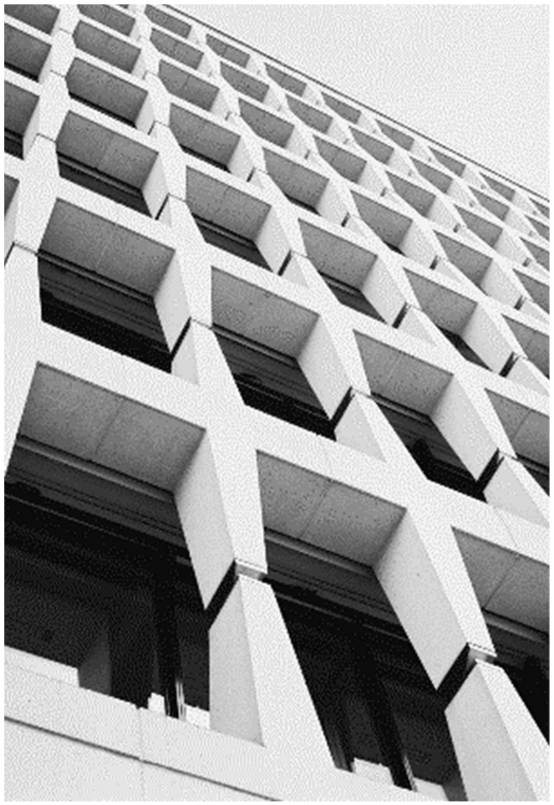


Image from Krinsky C. *Gordon Bunshaft of Skidmore, Owings & Merrill.* Architectural History Foundation and The Massachusetts Institute of Technology. 1988.

Key Issues
Columns placed beyond the glass on a 5-foot module to create a scale of pattern in keeping with the buildings around the site

Surface pattern
Regular grid

Panel type(s)
Non-rectangular panel

References

Krinsky C. *Gordon Bunshaft of Skidmore, Owings & Merrill.*

https://www.som.com/news/a_brussels_architect_explains_why_soms_banque_lambert_is_an_icon

# Bankkantoor ASLK/BNP Parisbas

Marcel Lambrichs
Brussels, Belgium, 1974

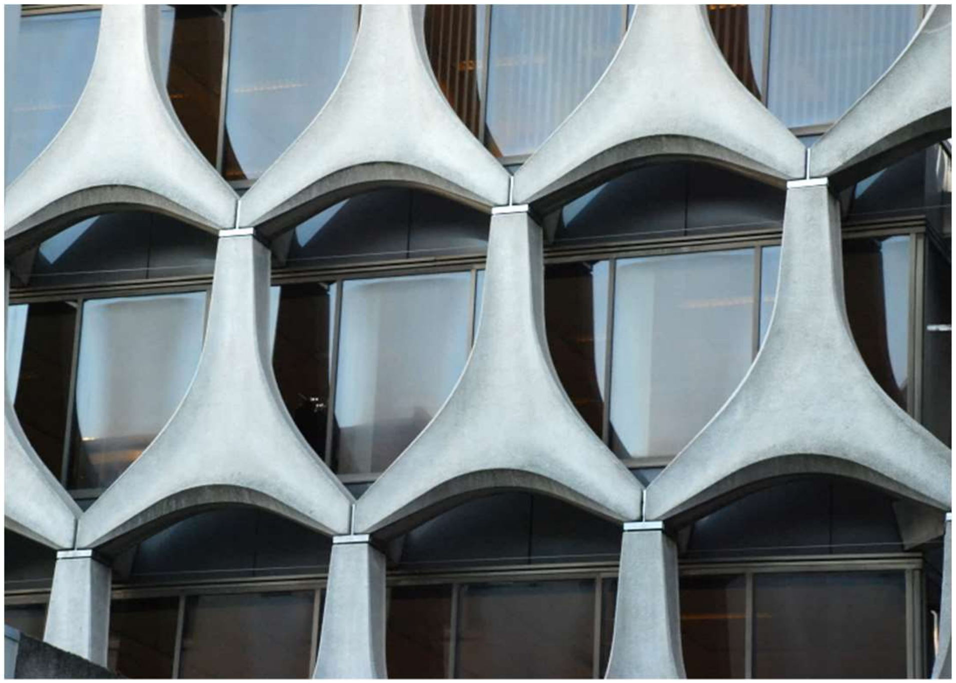


Image downloaded from
http://www.sosbrutalism.org/cms/16413733 in June 2018.

Key Issues
Because of collaboration between architect and fabricator, elements are both structural and aesthetic

Surface pattern
Diagonal

Panel type(s)
Non-rectangular panel, Loft, Notch

References

http://www.sosbrutalism.org/cms/16413733

http://docomomo.be/schokbeton2016/

# Brown Deer School Field House

Plunkett Raysich Architects
Brown Deer, Wisconsin, 2013

Image downloaded from https://www.prarch.com/our-work/education/k12/brown-deer-middle-high-school in June 2018.

Key Issues
Different colors within same panel

Surface pattern
Irregular grid (per regions)

Panel type(s)
Flat, Reveal

References

https://www.prarch.com/our-work/education/k12/brown-deer-middle-high-school

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=brown-deer-school-field-house

# Burntwood School

## Allford Hall Monaghan Morris
## London, England, 2014

Image downloaded from https://www.ahmm.co.uk/projectDetails/72/Burntwood-School in June 2018.

Key Issues
Façade units align with classroom proportions

Surface pattern
Irregular grid

Panel type(s)
Opening, Facet (negative), Corner (with facet and window)

References

https://www.ahmm.co.uk/projectDetails/72/Burntwood-School

# California State University San Bernardino College of Education

LPA

San Bernardino, California, 2008


Image downloaded from https://www.lpainc.com/work/california-state-university-san-bernardino-college-of-education in June 2018.

Key Issues
Curved panels
Control of reveal locations

Surface pattern
Regular grid

Panel type(s)
Flat, Opening, Reveal

References

https://www.lpainc.com/work/california-state-university-san-bernardino-college-of-education

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=college-of-education-csu-san-bernardino

# CBR building

## Constantin Brodzki and Marcel Lambrichs
## Brussels, Belgium, 1970

Image downloaded from
https://www.instagram.com/p/8JKr-iSuUE/ in June 2018.

Key Issues
Takes advantage of concrete's plasticity

Surface pattern
Regular grid

Panel type(s)
Opening (non rectangular), Loft

References

http://docomomo.be/schokbeton2016/

# CEDETEC

## LANDA Arquitectos
## Atizapan De Zaragoza, Mexico, 2011

Image downloaded from
http://www.landaarquitectos.mx/projects/91 in June 2018.

Key Issues
Curved panels

Surface pattern
Regular grid

Panel type(s)
Flat, Opening (to create “L” shape panels), Hole, Reveal

References

http://www.landaarquitectos.mx/projects/91

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=cedetec

# City of Loveland Service Center

## RNL Design

## Loveland, Colorado, 2014

Image downloaded from http://rnldesign.com/projects/city-of-loveland-service-center/ in June 2018.

Key Issues
Surface textures

Surface pattern
Regular grid

Panel type(s)
Openings (to create “L” and “C” shape panels)

References

http://rnldesign.com/projects/city-of-loveland-service-center/

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=city-of-loveland-service-center

# City of Miami College of Policing, Miami-Dade School of Law Studies, Homeland Security, and Forensic Sciences

AECOM

Miami, Florida, Date


Image downloaded from https://www.aecom.com/projects/city-miami-college-policing-miami-dade-school-law-studies-homeland-security-forensic-sciences/ in June 2018.

Key Issues
Incised signage
Surface textures

Surface pattern
Regular grid

Panel type(s)
Flat, Corner

References

https://www.aecom.com/projects/city-miami-college-policing-miami-dade-school-law-studies-homeland-security-forensic-sciences/

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=city-of-miami-college-of-policing-miami-dad-school

# Clark and Grand Hotels

HOK
Chicago, Illinois, 2013

Image downloaded from https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=clark-and-grand-hotels in June 2018.

Key Issues
Large scale pieces (facilitated tight urban site)

Surface pattern
Irregular grid

Panel type(s)
Flat, Reveal, Corner, Opening (to create complex shapes)

References

http://www.hok.com/design/type/hospitality/clark-and-grand-hotels/

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=clark-and-grand-hotels

# Cobank Center

Davis Partnership
Greenwood Village, Colorado, Date

Image downloaded from https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=cobank-center in June 2018.

Key Issues
Precast was cost effective solution to curtainwall
Curved panels

Surface pattern
Regular grid

Panel type(s)
Flat, Reveal, Relief area

References

http://davispartnership.com/projects/cobank-corporate-headquarters/

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=cobank-center

# Colony Square
## Jova Daniels Busby
## Atlanta, Georgia, 1972

Image downloaded from
http://www.sosbrutalism.org/cms/16879657 in June 2018.

Key Issues
One of the first multi-use developments in the southeastern United States

Surface pattern
Regular grid

Panel type(s)
Flat, Opening, Reveal, Facet

References

http://www.sosbrutalism.org/cms/16879657

http://docomomo-ga.weebly.com/blog/colony-square-part-i

# Colorado Center

Tryba Architects
Denver Colorado, 2017

Image downloaded from https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=colorado-center-tower-3 in June 2018.

Key Issues
Incorporation of curtainwall glass

Surface pattern
Irregular grid

Panel type(s)
Flat, Reveal, Opening, Relief area, Relief pattern, Rib

References

https://www.trybaarchitects.com/portfolio/colorado-center

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=colorado-center-tower-3

# Denver Hilton Hotel (now Sheraton Denver Downtown Hotel)

## I.M. Pei & Associates
## Denver, Colorado, 1960

Image downloaded from http://www.robertgeddesarchitect.com/_assets/pdf/articles/2015-DOCOMOMO-Schokbeton-Presentation.pdf in September 2018.

Key Issues
Cast stone made using aggregate collected during excavation of the site
Elaborate grids give the building the illusion of greater height than its twelve stories

Surface pattern
Regular grid (Running bond within regions)

Panel type(s)
Opening, Facet, Reveal

References

http://www.masonryofdenver.com/2014/10/denver-hilton-hotel/

# Department of Health, Education and Welfare Headquarters (Hubert H. Humphrey Federal Building)

## Marcel Breuer, Nolen-Swinburne and Associates, and Herbert Beckhard
## Washington, DC, 1976

Image downloaded from https://www.gsa.gov/real-estate/gsa-properties/visiting-public-buildings/hubert-h-humphrey-federal-building in June 2018.

Key Issues
Powerfully sculptural and rhythmically articulated

Surface pattern
Regular grid (which define regions)

Panel type(s)
Opening, Reveal, Facet

References


Hyman I. *Marcel Breuer, Architect: The career and the buildings.*

http://breuer.syr.edu/

https://www.gsa.gov/real-estate/gsa-properties/visiting-public-buildings/hubert-h-humphrey-federal-building

# Department of Housing and Urban Development Headquarters

## Marcel Breuer, Nolen-Swinburne and Associates, and Herbert Beckhard

## Washington, DC, 1968

Image downloaded from https://www.gsa.gov/historic-buildings/robert-c-weaver-federal-building-washington-dc in June 2018.

Key Issues
Double Y plan

Surface pattern
Regular grid

Panel type(s)
Opening, Reveal, Facet

References

Hyman I. *Marcel Breuer, Architect: The career and the buildings.*

http://breuer.syr.edu/

https://www.gsa.gov/historic-buildings/robert-c-weaver-federal-building-washington-dc

# Dior Miami Façade

## Barbaritobancel Architectes
## Miami, Florida, 2016


Image downloaded from http://www.barbaritobancel.com/projet/dior-miami-facade/ in June 2018.

Key Issues
Curved panels (within defined pattern)

Surface pattern
Irregular horizontal running bond

Panel type(s)
Flat (based on curve definition), Corner

References

http://www.barbaritobancel.com/projet/dior-miami-facade/

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=dior-miami-facade

# Dollar General Distribution Center

Leo A Daly
Bessemer, Alabama, 2012

Image downloaded from https://www.archdaily.com/337712/dollar-general-distribution-center-leo-a-daly in June 2018.

Key Issues
Linking pattern from panel to panel

Surface pattern
Regular grid

Panel type(s)
Relief pattern

References

http://www.leoadaly.com/portfolio/dollar-general-dc-alabama-design/

https://www.archdaily.com/337712/dollar-general-distribution-center-leo-a-daly

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=dollar-general-distribution-center

# Douglas L. McCrary Training Center

TOWNES + architect
Pensacola, Florida, 2014

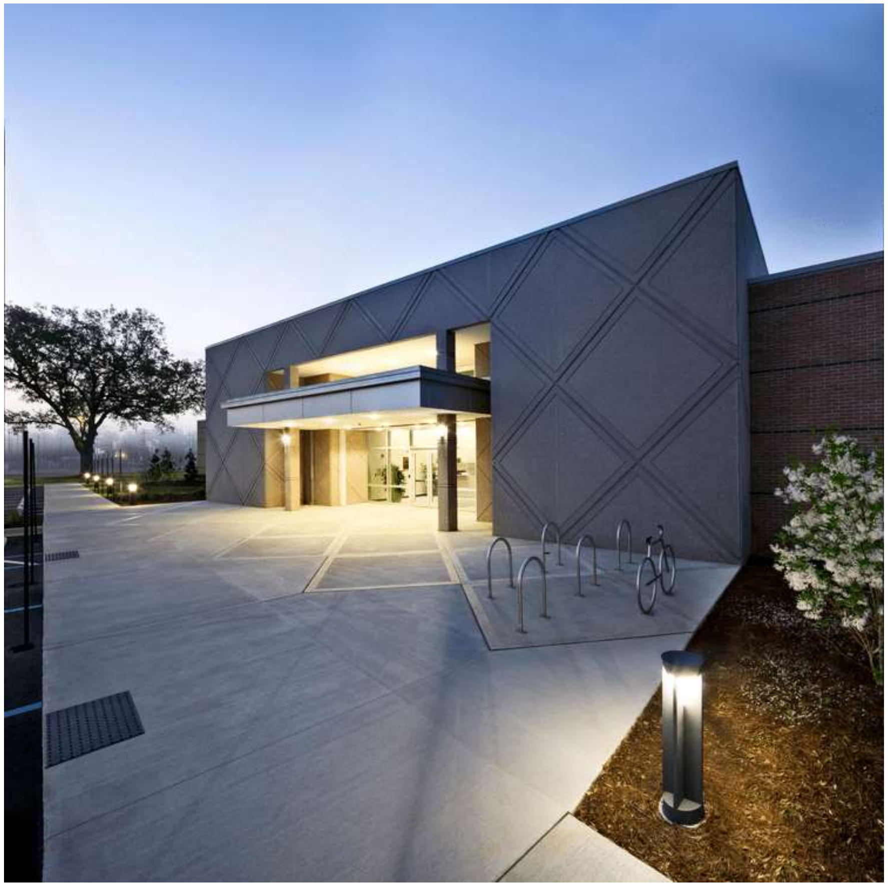


Image downloaded from http://townesplus.com/douglas-l-mccrary-training-center/ in June 2018.

Key Issues
Short time line

Surface pattern
Diagonals pattern on regular grid

Panel type(s)
Reveal

References

http://townesplus.com/douglas-l-mccrary-training-center/

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=gulf-power-douglas-l-mccrary-training-center

# Dubaski Career High School

Corgan
Grand Prairie, Texas, 2010

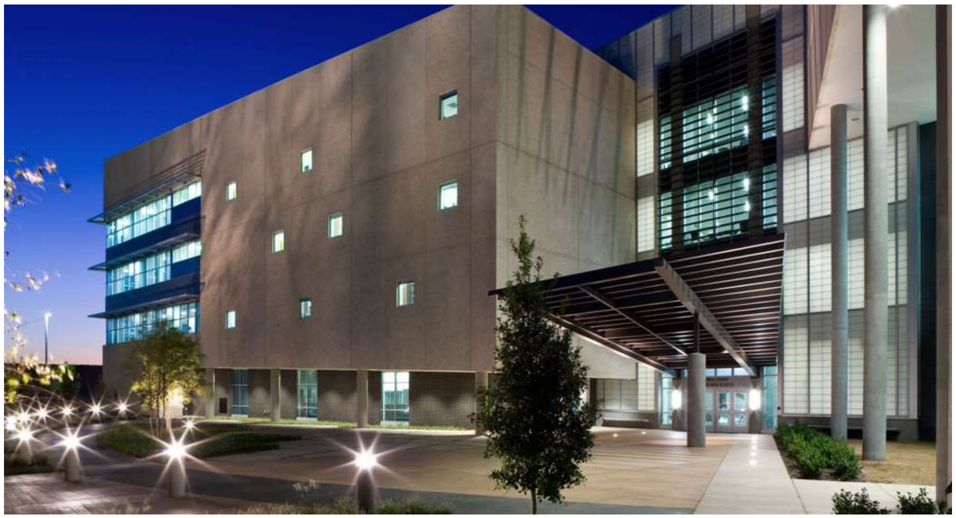


Image downloaded from https://www.corgan.com/projects/dubiski-high-school/ in June 2018.

Key Issues
Innovative shell finish

Surface pattern
Regular grid

Panel type(s)
Flat, Corner, Opening, Reveal

References

https://www.corgan.com/projects/dubiski-high-school/

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=grand-prairie-isd-dubiski-career-high-school

# Duke University Nasher Museum of Art

## Rafael Viñoly Architects
## Durham, North Carolina, 2005

Image downloaded from http://www.beckgroup.com/projects/nasher-museum-of-art-at-duke-university/ in June 2018.

Key Issues
Precast panels on the exterior extend into the interior atrium space

Surface pattern
Regular grid (note corners)

Panel type(s)
Flat, Reveal

References

http://vinoly.com/works/duke-university-nasker-museum-of-art/

http://www.beckgroup.com/projects/nasher-museum-of-art-at-duke-university/

# Dumbo Townhouses

## Alloy
## Brooklyn, New York, 2015

Key Issues
Ductal concrete panel facade

Surface pattern
Regular grid (by regions)

Panel type(s)
Facet (multiple per panel), Opening

References

http://www.alloyllc.com/work/dumbo-townhouses

https://www.archdaily.com/889815/dumbo-townhouses-alloy-design

Image downloaded from https://www.archdaily.com/889815/dumbo-townhouses-alloy-design in June 2018.

# Ennis (Ennis-Brown) Residence
Frank Lloyd Wright
Los Angeles, California, 1924

Image downloaded from
http://tommenterprises.tripod.com/id207.html in June 2018.

Key Issues
Craft and finish of intricately detailed panels

Surface pattern
Regular grid

Panel type(s)
Flat, Opening (non rectangular), Relief area

References

Moor A. *Frank Lloyd Wright at a glance: California Textile Block*

https://www.archdaily.com/77922/frank-lloyd-wrights-textile-houses

# ETS Student Housing
## Regis Cote et Associes
## Montreal, Canada, 2012

Key Issues
Tight schedule

Surface pattern
Regular grid

Panel type(s)
Opening, Reveal, Relief pattern (negative)

References

https://smithmidland.com/news/50-sw-precast/sw-panel-press-releases/377-ets-slenderwall-project-wins-pci-award

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=ets-student-housing

Image downloaded from https://smithmidland.com/news/50-sw-precast/sw-panel-press-releases/377-ets-slenderwall-project-wins-pci-award in June 2018.

# Eurocenter

## Ten Arquitectos
## Mexico City, Mexico, 2013

Image downloaded from http://www.ten-arquitectos.com/projects/151 in June 2018.

Key Issues
Fins

Surface pattern
Irregular grid

Panel type(s)
Flat

References

http://www.ten-arquitectos.com/projects/151

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=eurocenter

# First United Methodist Church

CDH Partners
Orlando, Florida, 2013

Image downloaded from http://www.cdhpartners.com/first-united-methodist-orlando-receives-2013-best-religious-structure-award/ in June 2018.

Key Issues
Tight site; panels delivered as needed

Surface pattern
Various regular and irregular grids based on regions

Panel type(s)
Flat, Relief area

References

http://www.cdhpartners.com/portfolio/first-united-methodist-orlando/

http://www.cdhpartners.com/first-united-methodist-orlando-receives-2013-best-religious-structure-award/

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=first-united-methodist-church

# Flaine Hotel

## Marcel Breuer and Robert F. Gatje
## Chamonix, France, 1968

Image downloaded from http://www.phaidon.com/agenda/architecture/articles/2016/january/19/when-marcel-breuer-built-a-brutalist-ski-resort/ in June 2018.

Key Issues
Precast was predetermined because of access to site

Surface pattern
Regular grid, Horizontal running bond

Panel type(s)
Opening, Facet

References

Hyman I. *Marcel Breuer, Architect: The career and the buildings.*

http://breuer.syr.edu/

# Florida International University Academic Health Center

Perkins + Will
Miami, Florida, 2015


Image downloaded from https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=florida-international-university-science-classroom-complex-bt-876 in June 2018.

Key Issues
Sun shade boxes based on sun study and digital model

Surface pattern
Regular grid

Panel type(s)
Opening, Reveal, Taper

References

https://perkinswill.com/work/florida-international-university-academic-health-center-4

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=florida-international-university-science-classroom-complex-bt-876

# Freeman Residence

## Frank Lloyd Wright
## Hollywood, California, 1924

Image downloaded from https://franklloydwright.org/site/samuel-freeman-house/ in June 2018.

Key Issues
Craft and finish of intricately detailed panels

Surface pattern
Regular grid

Panel type(s)
Flat, Opening (non rectangular), Relief area

References

Moor A. *Frank Lloyd Wright at a glance: California Textile Block.*

https://www.archdaily.com/77922/frank-lloyd-wrights-textile-houses

# Frost of Museum of Science

## Grimshaw and Rodriquez and Quirogo
## Miami, Florida, 2018

Image downloaded from https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Profile_Details.aspx?ID=214951 in June 2018.

Key Issues
Use of digital model and design assist

Surface pattern
Regular grid

Panel type(s)
Flat, Opening (non rectangular), Reveal, Facet (negative)

References

https://grimshaw.global/projects/patricia-and-phillip-frost-museum-of-science/

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Profile_Details.aspx?ID=214951

# Gordon Food Service Home Office

Integrated Architecture
Wyoming, Michigan, 2015

Image downloaded from http://www.intarch.com/project/gordon-food-service-corporate-headquarters/ in June 2018.

Key Issues
Reveals coordinated with openings

Surface pattern
Irregular grid

Panel type(s)
Flat, Opening, Reveal

References

http://www.intarch.com/project/gordon-food-service-corporate-headquarters/

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=gordon-food-service-home-office

# Hansberry College Prep

Wheeler Kearns Architects
Chicago, Illinois, 2013

Image downloaded from http://wkarch.com/project/hansberrycollegeprep/ in June 2018.

Key Issues
Cost effectiveness of precast

Surface pattern
Regular grid

Panel type(s)
Reveal, Relief area, Corner, Hole

References

http://wkarch.com/project/hansberrycollegeprep/

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=hansberry-college-prep

# Hempstead High School
FEH Associates
Dubuque, Iowa, 2016

Image downloaded from https://fehdesign.com/portfolio/hempstead-high-school/ in June 2018.

Key Issues
Form liner for custom patterns

Surface pattern
Regular grid

Panel type(s)
Flat, Opening, Reveal

References


https://fehdesign.com/portfolio/hempstead-high-school/

https://altusprecast.com/projects/hempstead-high-school/

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=hempstead-high-school-addition

# Hotel Residencial Nakâra

## Jacques Ferrier Architecture
## Cap d'Agde, France, 2015

Image downloaded from http://www.jacques-ferrier.com/en/projects/#nakara in June 2018.

Key Issues
Thin, very tall, highly perforated panels

Surface pattern
Custom

Panel type(s)
Opening, Perforation pattern

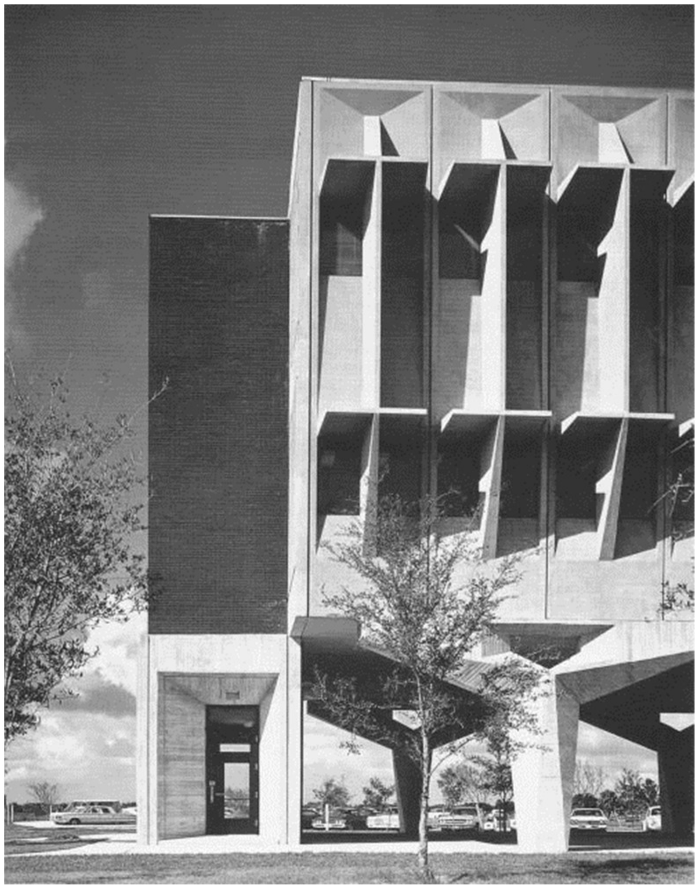
References


http://www.jacques-ferrier.com/en/projects/#nakara

https://www.archdaily.co/co/777576/hotel-residencial-nakara-jacques-ferrier-architectures

# IBM Administrative, Laboratory, and Manufacturing Facility

## Marcel Breuer and Robert F. Gatje
## Boca Raton, Florida, 1972



Key Issues
Two story tall panels

Surface pattern
Regular grid

Panel type(s)
Opening, Rib, Facet (positive and negative)

References

Hyman I. *Marcel Breuer, Architect: The career and the buildings.*

http://breuer.syr.edu/

Image from Hyman I. *Marcel Breuer, Architect: The career and the buildings.* Harry N Abrams Inc Publishers. 2001.

# IBM Research Center
## Marcel Breuer and Robert F. Gatje
## La Gaude, France, 1962

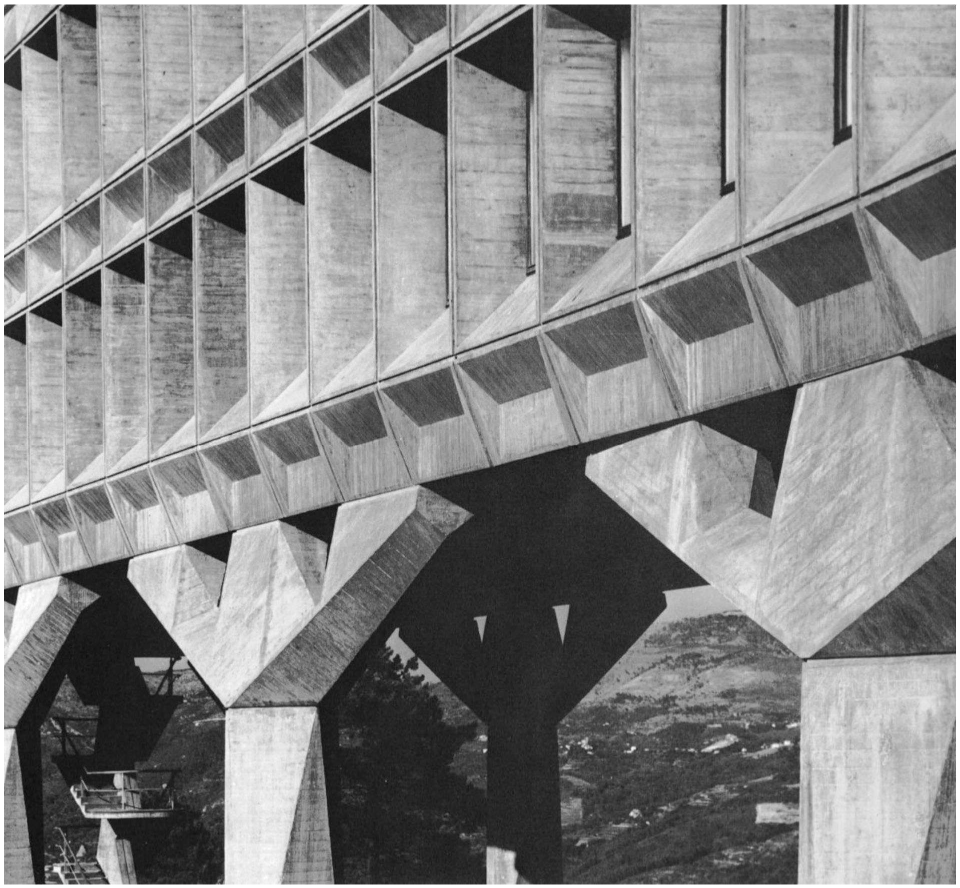


Image from Hyman I. *Marcel Breuer, Architect: The career and the buildings.* Harry N Abrams Inc Publishers. 2001.

Key Issues
Deep panels accommodate mechanical systems

Surface pattern
Irregular grid (horizontal regions)

Panel type(s)
Opening, Reveal, Facet, Taper

References

Hyman I. *Marcel Breuer, Architect: The career and the buildings.*

http://breuer.syr.edu/

# Indiana University Stadium North End Zone

Ratio Design
Bloomington, Indiana, 2009

Image downloaded from https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=indiana-university-stadium-north-end-zone-addition in June 2018.

Key Issues
Form liners to create limestone look

Surface pattern
Irregular grid

Panel type(s)
Opening, Facet (positive), Relief area, Reveal

References

http://www.ratiodesign.com/project/iu-memorial-stadium-north-endzone

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=indiana-university-stadium-north-end-zone-addition

# Internal Revenue Service Center

HOK and BNIM
Kansas City, Missouri, 2007

Image downloaded from http://www.hok.com/design/type/government/internal-revenue-service-center/ in June 2018.

Key Issues
Various textures

Surface pattern
Regular grid

Panel type(s)
Opening, Relief area

References

http://www.hok.com/design/type/government/internal-revenue-service-center/

https://www.bnim.com/project/internal-revenue-service-kansas-city-campus

# Italy Pavilion for the Milan Expo

Nemesi Studio
Milan, Italy, 2015

Image downloaded from http://www.nemesistudio.it/en/projects/type/culture/item/714-italy-pavilion-expo-2015-milan.html in June 2018.

Key Issues
700 unique panels

Surface pattern
Irregular quad horizontal

Panel type(s)
Gesture, Opening, Relief area

References


http://www.nemesistudio.it/en/projects/type/culture/item/714-italy-pavilion-expo-2015-milan.html

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=italy-pavilion-for-the-milan-expo

# James F. Battin United States Courthouse

NBBJ

Billings, Montana, 2012

Image downloaded from http://www.nbbj.com/work/us-federal-courthouse-billings/ in June 2018.

Key Issues
Fastest delivery of a federal courthouse

Surface pattern
Various based on region

Panel type(s)
Flat, Reveal, Opening, Facet

References

http://www.nbbj.com/work/us-federal-courthouse-billings/

https://www.mortenson.com/seattle/projects/james-f-battin-federal-courthouse

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=james-f-battin-united-states-courthouse

# JE Dunn Corporate Headquarters

HOK and BNIM
Kansas City, Missouri, 2009

Image downloaded from https://www.hok.com/design/region/united-states/je-dunn-construction-headquarters/ in June 2018.

Key Issues
Textured form liner
Three different precasters; wall panels, parking structure, hollow core slabs

Surface pattern
Custom quad

Panel type(s)
Flat, Opening, Reveal

References

https://www.bnim.com/project/je-dunn-construction-world-headquarters-0

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=je-dunn-corporate-headquarters

# Judicial Council of California, Superior Court of California, County of Santa Clara, Family Justice Center Courthouse

ZFG Architects
San Jose, California, 2016


Image downloaded from https://www.zgf.com/project/jcc-family-courthouse/ in June 2018.

Key Issues
Custom connections to withstand blasts

Surface pattern
Regular grid

Panel type(s)
Flat, Reveal

References

https://www.zgf.com/project/jcc-family-courthouse/

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=santa-clara-family-justice-center

# Kauffman Center for the Performing Arts

Safdie Architects and BNIM
Kansas City, Missouri, 2011


Image downloaded from https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=kauffman-center-for-the-performing-arts in June 2018.

Key Issues
Curved panels

Surface pattern
Regular grid

Panel type(s)
Flat (non rectangular)

References

https://www.safdiearchitects.com/projects/kauffman-center-for-the-performing-arts

https://www.bnim.com/project/kauffman-center-performing-arts

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=kauffman-center-for-the-performing-arts

# King Abdullah Academy

## Bowie Gridley Architects
## Herndon, Virginia, 2016

Image downloaded from http://www.bowiegridley.com/king-abdullah-academy/ in June 2018.

Key Issues
Intricate patterns

Surface pattern
Varies based on region

Panel type(s)
Flat, Reveal, Relief pattern

References

http://www.bowiegridley.com/king-abdullah-academy/

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=king-abdullah-academy

# L.A. Marriott
## GBD Architects
## Los Angeles, California, 2014

Image downloaded from http://www.gbdarchitects.com/portfolio-item/la-marriott/ in June 2018.

Key Issues
Off-site pre-glazing

Surface pattern
Staggered quads horizontal

Panel type(s)
Opening, Reveal, Relief area

References

http://www.gbdarchitects.com/portfolio-item/la-marriott/

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=l-a-live-marriott-courtyard-and-residence-inn

# Lincoln Park 2550

Lucien Lagrange Studio
Chicago, Illinois, 2012


Image downloaded from http://www.skyscrapercenter.com/building/lincoln-park-2550/9937 in June 2018.

Key Issues
Curved panels

Surface pattern
Irregular grid

Panel type(s)
Reveal, Relief pattern (negative), Opening (multiple per panel)

References

http://www.lucienlagrange.com/lincoln-park-2550-2550-north-lakeview-avenue-lincoln-park-chicago-home

http://www.skyscrapercenter.com/building/lincoln-park-2550/9937

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=2550-n-lakeview-drive

# Maritime and Seafood Industry Museum

H3 Hardy Collaboration Architecture
Biloxi, Mississippi, 2014


Image downloaded from https://www.h3hc.com/mism in June 2018.

Key Issues
Large panels – 10’ wide by 25’ tall

Surface pattern
Regular grid

Panel type(s)
Flat, Corner (not 90 degrees)

References

https://www.h3hc.com/mism

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=maritime-and-seafood-industry-museum

# Millard Residence (La Miniatura)

Frank Lloyd Wright
Pasadena, California, 1924

Image downloaded from http://www.messynessychic.com/2018/05/01/murder-in-the-blueprints-of-frank-lloyd-wright/ in June 2018.

Key Issues
Craft and finish of intricately detailed panels

Surface pattern
Irregular grid

Panel type(s)
Flat, Opening (non rectangular), Relief area

References


Moor A. *Frank Lloyd Wright at a glance: California Textile Block.*

https://www.archdaily.com/77922/frank-lloyd-wrights-textile-houses

# Milwaukee Tool Headquarters

## Stephen Perry Smith Architects
## Brookfield, Wisconsin, 2017

Image downloaded from https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=milwaukee-tool-headquarters in June 2018.

Key Issues
Panels cast while site work was already underway

Surface pattern
Irregular grid

Panel type(s)
Reveal, Relief area

References

https://www.spsarchitects.com/copy-of-portfolio

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=milwaukee-tool-headquarters

# Minnesota Senate Building

BWBR

St. Paul, Minnesota, Date

Image downloaded from https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=minnesota-senate-building in June 2018.

Key Issues
Many L shape panels

Surface pattern
Irregular grid (by region)

Panel type(s)
Flat, Reveal, Opening, Corner (inside and outside)

References

http://www.bwbr.com/portfolio/minnesota-senate-building/

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=minnesota-senate-building

# MuCEM

## Rudy Ricciotti
## Marseille, France, 2012

Image downloaded from
http://rudyricciotti.com/projet/musee-des-civilisations-deurope-et-de-mediterranee#!/rudyricciotti.com/wp
in September 2018.

Key Issues
Thin, highly irregularly perforated panels

Surface pattern
Regular grid

Panel type(s)
Opening, Perforation pattern

References

http://rudyricciotti.com/projet/musee-des-civilisations-deurope-et-de-mediterranee#!/rudyricciotti.com/wp

https://www.archdaily.com/400727/mucem-rudy-ricciotti

# Nanyang Technological University Learning Hub (The Hive)

## Heatherwick Studio and CPG Corporation
## Singapore, Malaysia, 2013


Image downloaded from http://www.heatherwick.com/projects/buildings/learning-hub-the-hive/ in June 2018.

Key Issues
1000 unique panels

Surface pattern
Staggered grid horizontal

Panel type(s)
Reveal, Relief pattern (negative)

References

http://www.heatherwick.com/projects/buildings/learning-hub-the-hive/

https://www.cpgcorp.com.sg/our-work/education

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=nanyang-technological-university-learning-hub-the-hive

# Osage Prairie YMCA Natatorium Addition
## SFS Architecture
## Nevada, Montana, 2009

Key Issues
Limited budget

Surface pattern
Regular grid

Panel type(s)
Opening, Relief area

References

https://www.sfsarch.com/projects/recreation/osage-prairie-ymca-natatorium-addition/

Image downloaded from https://www.sfsarch.com/projects/recreation/osage-prairie-ymca-natatorium-addition/ in June 2018.

# Pan Am Building

## Emery Roth & Sons, Pietro Belluchi and Walter Gropius
## New York, New York, 1963

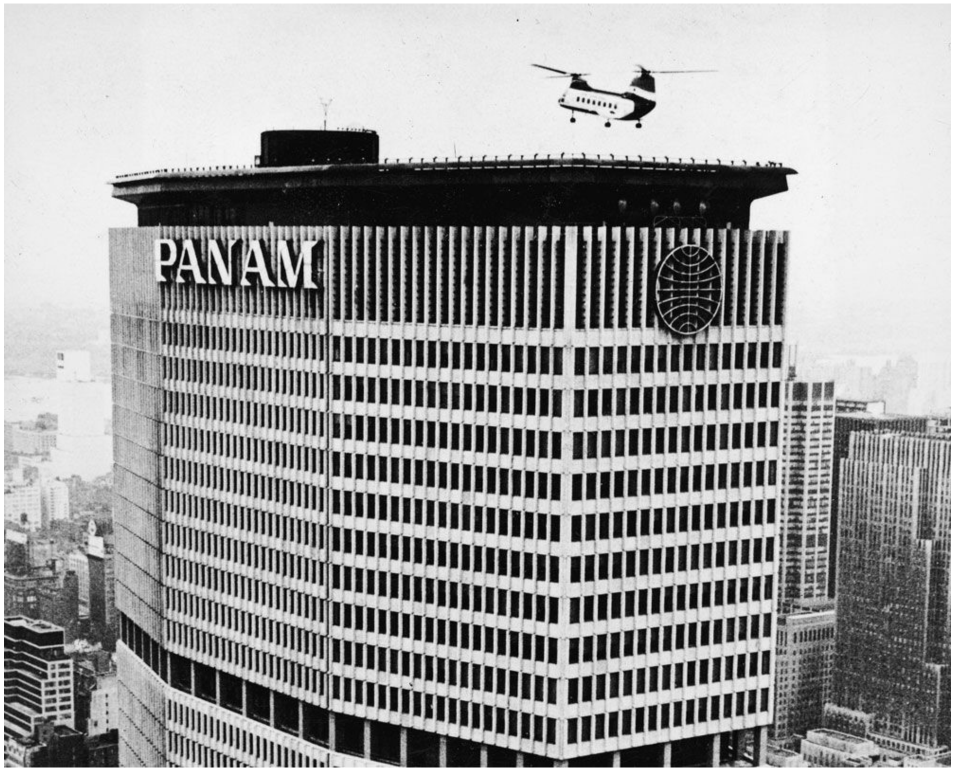



Image downloaded from https://www.6sqft.com/great-game-changers-how-the-metlife-building-redefined-midtowns-architecture/ in June 2018.

Key Issues
Very bold pre-cast concrete facade

Surface pattern
Regular grid

Panel type(s)
Opening, Rib, Reveal

References

https://www.6sqft.com/great-game-changers-how-the-metlife-building-redefined-midtowns-architecture/

# Paragon Santa Fe

IDEA Asociados Arquitectos
Sante Fe, Mexico, 2009

Image downloaded from https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=conjunto-paragon in June 2018.

Key Issues
Flexible form casting

Surface pattern
Regular grid

Panel type(s)
Opening, Reveal, Relief area

References


http://www.ideasociados.com/english/paragon.html

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=conjunto-paragon

http://www.skyscrapercenter.com/building/paragon-santa-fe/4714

# Perot Museum of Nature and Science

## Morphosis Architects
## Dallas, Texas, 2012

Image downloaded from https://www.morphosis.com/architecture/125/ in June 2018.

Key Issues
Standard panel to maximizes modularity, interchangeability, and the appearance of a complex, dynamic façade
Design assist

Surface pattern
Irregular

Panel type(s)
Reveal, Opening, Relief pattern (positive), Gesture

References


https://www.morphosis.com/architecture/125/

https://www.archdaily.com/295662/perot-museum-of-nature-and-science-morphosis

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=perot-museum-of-nature-and-science

https://www.autodesk.com/redshift/design-assist/

# Philadelphia Police Department Headquarters (Roundhouse)

## Geddes, Brecher, Qualls and Cunningham
## Philadelphia, Pennsylvania, 1959

Image downloaded from http://www.robertgeddesarchitect.com/_assets/pdf/articles/2015-DOCOMOMO-Schokbeton-Presentation.pdf in September 2018.

Key Issues
Rotation of wedge-shaped precast concrete elements around three elevator cores

Surface pattern
Regular grid

Panel type(s)
Opening, Facet, Reveal, Relief

References

Geddes, Brecher, Qualls, Cunningham. *Process: Architecture: No 62.*

http://planphilly.com/eyesonthestreet/2016/05/06/building-stories-the-roundhouse

# Pierresvives

## Zaha Hadid Architects
## Montpellier, France, 2012

Image downloaded from http://www.zaha-hadid.com/architecture/pierrevives/ in June 2018.

Key Issues
Complex curving form

Surface pattern
Regular grid

Panel type(s)
Flat

References

http://www.zaha-hadid.com/architecture/pierrevives/

http://archweekpeopleandplaces.blogspot.com/2012/11/zaha-hadid-architects-in-montpellier.html

https://www.archdaily.com/273554/pierres-vives-zaha-hadid-architects

# Place de L'Escarpement

## Pierre Martin & Associes Architectes
## Quebec, Canada, 2010

Image downloaded from http://pmaarchitectes.com/projets-edifices-a-bureaux/place-de-l-escarpement-1 in June 2018.

Key Issues
Digital model controlled shape and depth of waves
Pigment and sandblasting enhance the look

Surface pattern
Regular grid

Panel type(s)
Reveal, Opening, Relief pattern (positive)

References

http://pmaarchitectes.com/projets-edifices-a-bureaux/place-de-l-escarpement-1

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=place-de-lescarpement

# Residences Le Saint-Jude

## Eric Painchaud Architecte and Associes
## Alma, Canada, 2010

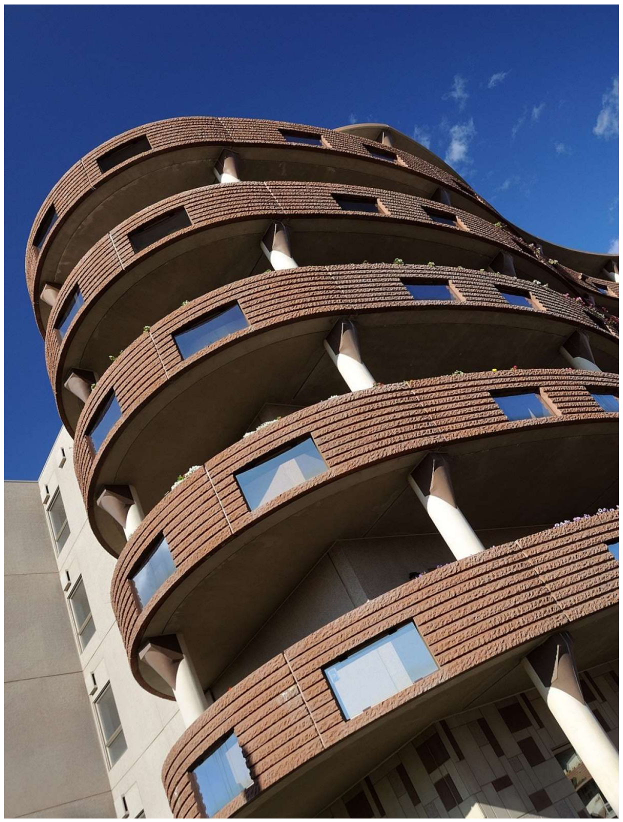


Image downloaded from http://eparchitecte.com/residentiel-multi-residentiel/residences-le-saint-jude-(alma).html in June 2018.

Key Issues
Curved panels
Precast part of seismic and wind force systems

Surface pattern
Regular grid

Panel type(s)
Opening, Relief pattern (negative), Reveal

References

http://eparchitecte.com/residentiel-multi-residentiel/residences-le-saint-jude-(alma).html

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=residence-le-saint-jude

# Roseville City Hall Annex

LPAS Architect
Roseville, California, 2016

Image downloaded from http://www.lpas.com/projects/downtown-roseville-316-vernon-street-office in June 2018.

Key Issues
All precast building

Surface pattern
Irregular grid based on region

Panel type(s)
Flat, Reveal, Relief area

References

http://www.lpas.com/projects/downtown-roseville-316-vernon-street-office

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=roseville-city-hall-annex

# Sarget-Ambrine Headquarters and Pharmaceutical Laboratories

## Marcel Breuer and Robert F. Gatje
## Merignac, France, 1967

Image downloaded from http://astudejaoublie.blogspot.com/2015/02/merignac-laboratoires-pharmaceutiques.html in June 2018.

Key Issues
Curved building and pilotis (typical of Breuer in this period)

Surface pattern
Regular grid

Panel type(s)
Opening, Reveal, Facet (positive and negative)

References

Hyman I. *Marcel Breuer, Architect: The career and the buildings.*

http://breuer.syr.edu/

# Simons Galeries d'Anjou

Lemaymichaud
Montreal, Canada, 2013


Image downloaded from
http://www.lemaymichaud.com/en/projets/commercial-en/simons-anjou/ in September 2018.

Key Issues
Insulated panels

Surface pattern
Regular grid

Panel type(s)
Perforation pattern

References

http://www.lemaymichaud.com/en/projets/commercial-en/simons-anjou/

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=la-maison-simons

# Storer Residence

## Frank Lloyd Wright
## Hollywood, California, 1924

Image downloaded from https://www.curbed.com/2015/2/25/9987818/frank-lloyd-wright-house-sale in September 2018.

Key Issues
Craft and finish of intricately detailed panels

Surface pattern
Irregular grid

Panel type(s)
Flat, Opening (non rectangular), Relief area

References

Moor A. *Frank Lloyd Wright at a glance: California Textile Block.*

https://www.archdaily.com/77922/frank-lloyd-wrights-textile-houses

# Suffolk University 20 Somerset Street
NBBJ
Boston, Massachusetts, 2015

Image downloaded from http://www.nbbj.com/work/suffolk-university-academic-building/ in June 2018.

Key Issues
Dozens of precast panel options modeled digitally

Surface pattern
Staggered quad horizontal

Panel type(s)
Facet (negative)

References

http://www.nbbj.com/work/suffolk-university-academic-building/

# SUNY Buffalo Faculty of Engineering and Applied Science Building Complex

## Marcel Breuer and Robert F. Gatje
## Amherst, Massachusetts, 1978

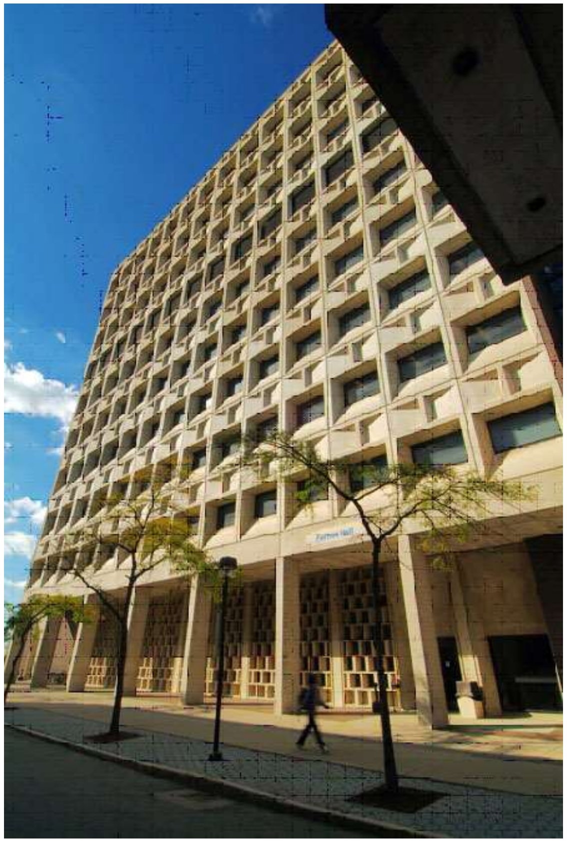


Image downloaded from https://www.drupal.docomomo-us.org/news/fiche_architects_21 in June 2018.

Key Issues
Part of long term master plan for SUNY Buffalo

Surface pattern
Regular grid

Panel type(s)
Opening, Reveal, Facet (multiple per panel)

References

Hyman I. *Marcel Breuer, Architect: The career and the buildings.*

http://breuer.syr.edu/

# Teen Living Programs (Belfort House)

Hartshorne Plunkard Architecture
Chicago, Illinois, 2010

Image downloaded from
http://www.hparchitecture.com/projects/residential/new/teen-living-programs-belfort-house/ in June 2018.

Key Issues
Accelerated construction schedule

Surface pattern
Vertical running bond

Panel type(s)
Flat, Opening, Reveal, Relief area

References

http://www.hparchitecture.com/projects/residential/new/teen-living-programs-belfort-house/

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=teen-living-programs

# Terrace 459 at Parkside of Old Town

## Landon Bone Baker Architects
## Chicago, Illinois, 2016

Image downloaded from https://www.landonbonebaker.com/work/terrace-459-parkside-of-old-town/ in June 2018.

Key Issues
All precast building
Interesting pattern within constraints of budget

Surface pattern
Staggered quads horizonal

Panel type(s)
Opening, Reveal, Relief area

References

https://www.landonbonebaker.com/work/terrace-459-parkside-of-old-town/

http://www.architectmagazine.com/project-gallery/terrace-459_o

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=terrace-459-at-parkside-of-old-town

# Textilmacher
## tillicharchitektur
## Munich, Germany, 2013

Image downloaded from http://www.tillicharchitektur.de/categories/projekte in June 2018.

Key Issues
Short construction period
Seamless, sharp edged, pore free

Surface pattern
Custom irregular quads

Panel type(s)
Flat, Opening, Reveal, Facet

References

http://www.tillicharchitektur.de/categories/projekte

https://www.archdaily.com/536964/textilmacher-tillicharchitektur/

# The Broad Museum

Diller Scofidio + Renfro
Los Angeles, California, 2015

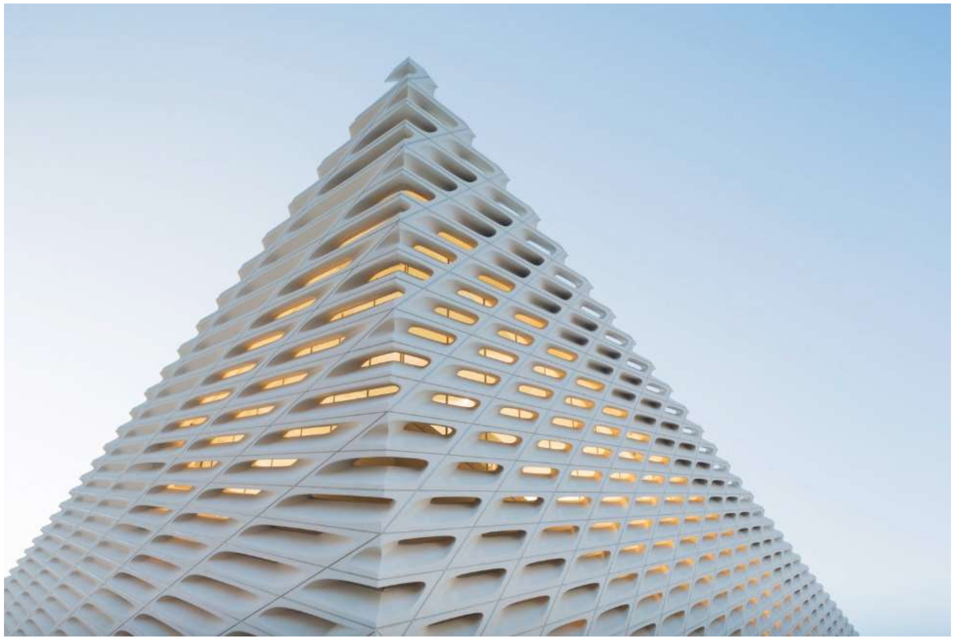


Image downloaded from https://dsrny.com/project/the-broad?index=false&section=projects&tags=cultural in June 2018.

Key Issues
Veil with conical light openings
Glass fiber reinforced concrete (GFRC)
Scanning forms to verify with digital model for accuracy

Surface pattern
Modified diagonal

Panel type(s)
Opening (not extrusion), Reveal

References


https://dsrny.com/project/the-broad?index=false&section=projects&tags=cultural

https://www.archdaily.com/772778/the-broad-diller-scofidio-plus-renfro

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=the-broad-museum

# The Century
## Robert A.M Stern Architects
## Los Angeles, California, 2010


Image downloaded from http://www.ramsa.com/projects/project/century in September 2018.

Key Issues
Curved panels
Concave and convex panels

Surface pattern
Irregular grid

Panel type(s)
Reveal, Relief area, Relief pattern (negative), Opening

References

http://www.ramsa.com/projects/project/century

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=the-century

# The National World War II Museum

Voorsanger Architects
New Orleans, Louisiana, 2011

Image downloaded from https://www.satpon.com/the-national-world-war-ii-museum-expansion/ in September 2018.

Key Issues
Large scale panels with angular edges and joints

Surface pattern
Staggered grid horizontal

Panel type(s)
Flat (rectangular and non rectangular), Opening, Reveal

References


http://voorsanger.com/recent_projects/4

https://www.satpon.com/the-national-world-war-ii-museum-expansion/

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=the-national-world-war-ii-museum-phase-iv-expansion

# The Ohio State University South Campus Chiller Plant

Ross Barney Architects
Columbus, Ohio, 2013

Image downloaded from http://www.r-barc.com/projects/osu-south-campus-chiller-plant/ in June 2018.

Key Issues
11 different panel types

Surface pattern
Staggered irregular grid horizonal

Panel type(s)
Flat, Reveal, Opening, Facet (negative), Notch

References

http://www.r-barc.com/projects/osu-south-campus-chiller-plant/

https://www.archdaily.com/408850/south-campus-chiller-plant-at-osu-ross-barney-architects

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=the-ohio-state-university-chiller-plant

# Torin Corporation

## Marcel Breuer and Hamilton P. Smith and Andre and Jean Polak
## Nivelles, Belgium, 1964

Image downloaded from
http://docomomo.be/schokbeton2016/ in June 2018.

Key Issues
Schokbeton method
Deep panels – 5’ deep x 20’ tall

Surface pattern
Regular grid

Panel type(s)
Opening, Facet (positive and negative), Rib, Relief

References

Hyman I. *Marcel Breuer, Architect: The career and the buildings.*

http://breuer.syr.edu/

# Torin Corporation Administration Building
## Marcel Breuer and Herbert Beckhard
## Torrington, Connecticut, 1966

Image from Hyman I. *Marcel Breuer, Architect: The career and the buildings.* Harry N Abrams Inc Publishers. 2001.

Key Issues
Panels function as sunshades and house fan coil units

Surface pattern
Regular grid

Panel type(s)
Opening, Facet (positive and negative), Reveal

References

Hyman I. *Marcel Breuer, Architect: The career and the buildings.*

http://breuer.syr.edu/

# Tour Towers

Barkow Leibinger
Berlin, Germany, 2012

Image downloaded from https://www.archdaily.com/282457/tour-total-barkow-leibinger-architects in June 2018.

Key Issues
Intelligent facade system

Surface pattern
Regular grid

Panel type(s)
Opening, Reveal, Facet

References

http://www.barkowleibinger.com/archive/view/tour_total

https://www.archdaily.com/282457/tour-total-barkow-leibinger-architects

# U.S. Embassy Dublin

## John M Johansen
## Dublin, Ireland, 1964

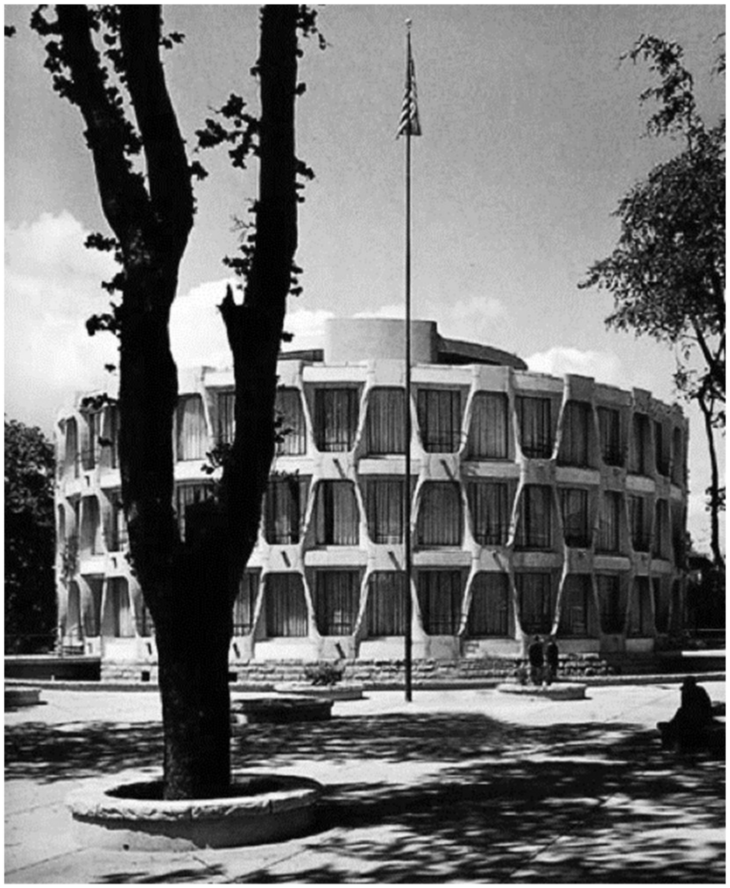


Image downloaded from http://johnmjohansen.com/US-Embassy-Dublin.html in June 2018.

Key Issues
Basic element is a twisted I, which, multiplied and dovetailed together, turns window frames into walls

Surface pattern
Regular grid

Panel type(s)
Loft

References

http://johnmjohansen.com/US-Embassy-Dublin.html

# U.S. Embassy London

Eero Saarinen
London, England, 1960

Image downloaded from https://www.curbed.com/2014/12/5/10014818/us-embassy-london-eero-saarinen-photos in June 2018.

Key Issues
Facade composed of precast concrete window frames alternated with operable aluminum windows

Surface pattern
Running bond horizontal

Panel type(s)
Opening, Corner

References

https://www.curbed.com/2014/12/5/10014818/us-embassy-london-eero-saarinen-photos

# U.S. Federal Courthouse
## H3 Hardy Collaboration Architecture
## Jackson, Mississippi, 2010

Image downloaded from https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=u-s-federal-courthouse in June 2018.

Key Issues
Large "E" shape panels

Surface pattern
Regular grid

Panel type(s)
Opening, Relief pattern (positive), Facet

References

https://www.h3hc.com/jackson/ro4ml4jug32ux7j15d4xy50v69roti

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=u-s-federal-courthouse

# UCSF Medical Center at Mission Bay

Stantec

San Francisco, California, 2015


Image downloaded from https://www.ucsf.edu/news/2017/08/407991/ucsf-medical-center-ranks-best-hospital-california in June 2018.

Key Issues

Large panels ranging from 4’ by 10’ feet to 4’ by 32’

Surface pattern

Regular grid based on regions

Panel type(s)

Flat, Opening, Reveal

References

https://www.stantec.com/en/projects/united-states-projects/u/ucsf-medical-center-at-mission-bay-and-benioff-childrens-hospital

https://www.ucsf.edu/news/2017/08/407991/ucsf-medical-center-ranks-best-hospital-california

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=university-of-california-at-san-francisco-medical-center-at-mission-bay

# UCSF Mission Hall: Global Health & Clinical Sciences Building

WRNS Studio
San Francisco, California, 2014

Image downloaded from https://www.wrnsstudio.com/project/ucsf-mission-hall-global-health-and-clinical-sciences-building in June 2018.

Key Issues
GFRC panels, glass, and metal panels in one unit

Surface pattern
Irregular staggered quads horizontal

Panel type(s)
Flat, Opening, Reveal

References

https://www.wrnsstudio.com/project/ucsf-mission-hall-global-health-and-clinical-sciences-building

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=ucsf-mission-hall-global-health-sciences-building

# Universal Alloy Light Press Plant
## Querkraft
## Ball Ground, Georgia, 2017

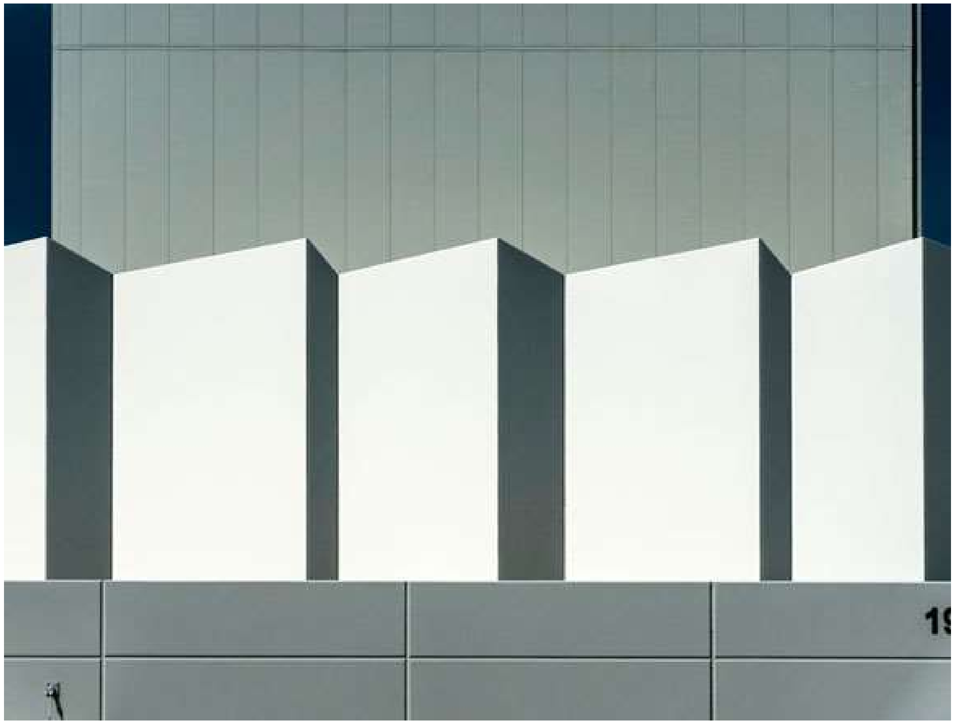


Image downloaded from
http://www.querkraft.at/?story=2581&details=1 in June 2018.

Key Issues
Façade appears 3D through innovative use of color, texture, and design

Surface pattern
Irregular grid

Panel type(s)
Flat, Reveal, Opening

References

http://www.querkraft.at/?story=2581&details=1

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=universal-alloy-light-press-plant

# University of Chicago Campus North Residential Commons

Studio Gang
Chicago, Illinois, 2016

Image downloaded from http://studiogang.com/project/university-of-chicago-campus-north-residential-commons in June 2018.

Key Issues
Contemporary façade informed by neo-Gothic tradition

Surface pattern
Staggered quads horizontal

Panel type(s)
Opening, Facet, Reveal

References


http://studiogang.com/project/university-of-chicago-campus-north-residential-commons

https://www.archdaily.com/799351/university-of-chicago-campus-north-residential-commons-studio-gang

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=university-of-chicago-north-residential-commons

# University of Florida Health Shands Cancer Hospital

Flad Architects
Gainesville, Florida, 2017

Image downloaded from https://m.ufhealth.org/uf-health-shands-cancer-hospital in June 2018.

Key Issues
Use of digital model for coordination with other facades trades and structural system

Surface pattern
Regular grid

Panel type(s)
Flat, Reveal, Relief area (with brick facing)

References

https://www.flad.com/projects/detail.php?project=shands_hospital

https://m.ufhealth.org/uf-health-shands-cancer-hospital

# University of Houston Health and Biomedical Sciences Buil

Shepley Bulfinch
Houston, Texas, 2014

Key Issues
Beveled façade to play with light and shadow

Surface pattern
Regular grid

Panel type(s)
Flat, Facet (negative and positive), Opening

References

http://www.shepleybulfinch.com/projects/university-of-houston-health-and-biomedical-sciences-buildings-1-2/

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=university-of-houston-health-and-biomedical-sciences-building

Image downloaded from http://www.shepleybulfinch.com/projects/university-of-houston-health-and-biomedical-sciences-buildings-1-2/ in June 2018.

# University of Kansas Capitol Federal Hall

Gensler and GastingerWalker&
Lawrence, Kansas, 2016

Image downloaded from
http://www.gastingerwalker.com/university-of-kansas-client
in June 2018.

Key Issues
Weight of panels braced to structural steel

Surface pattern
Irregular grid (by region)

Panel type(s)
Flat, Facet (negative)

References

http://www.gastingerwalker.com/university-of-kansas-client

https://www.gensler.com/projects/university-of-kansas-school-of-business?q=kansas

https://www.pci.org/PCI/Projects/Project_Profiles/PCI/Project_Resources/Project_Profile/Project_Central.aspx?hkey=b2d0bf14-394e-43f7-a8c1-83dc74724c19&project=capitol-federal-hall-university-of-kansas

# University of Massachusetts Murray Lincoln Campus Center

## Marcel Breuer and Herbert Beckhard
## Amherst, Massachusetts, 1970

Image downloaded from https://www.flickr.com/photos/32215181@N08/6686012713 in June 2018.

Key Issues
Contrasts in textures and scales, rhythmic variations

Surface pattern
Irregular grid (by region)

Panel type(s)
Opening, Facet, Reveal

References


Hyman I. *Marcel Breuer, Architect: The career and the buildings.*

http://breuer.syr.edu/

# Waldorf Astoria Chicago

## Lucien Lagrange Studio
## Chicago, Illinois, 2009

Image downloaded from http://www.lucienlagrange.com/waldorf-astoria-chicago-11-east-walton-street-gold-coast-chicago-info/ in June 2018.

Key Issues
Highly textured facades

Surface pattern
Running bond horizontal

Panel type(s)
Flat, Reveal, Opening

References

http://www.lucienlagrange.com/waldorf-astoria-chicago-11-east-walton-street-gold-coast-chicago-info/

# Wisconsin Athletic Center

Eppstein Uhen Architects
Menomonee Falls, Wisconsin, 2013

Image downloaded from https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=ryan-medical-wellness-center in June 2018.

Key Issues
Accelerated schedule

Surface pattern
Irregular grid

Panel type(s)
Flat, Opening, Reveal, Relief area

References

http://www.eua.com/projects/wisconsin-athletic-center-menomonee-falls/

https://www.pci.org/PCI/Project_Resources/Project_Profile/Project_Central.aspx?project=ryan-medical-wellness-center

# Yale University Becton Engineering and Applied Science Center

Marcel Breuer and Hamilton P. Smith
New Haven, Connecticut, 1970

Key Issues
Textural variations among panels

Surface pattern
Regular grid, Irregular grid

Panel type(s)
Facet (negative and positive), Reveal, Opening

References

Hyman I. *Marcel Breuer, Architect: The career and the buildings.*

http://breuer.syr.edu/

http://www.sosbrutalism.org/cms/16246931

Image downloaded from
http://www.sosbrutalism.org/cms/16246931 in June 2018.

# APPENDIX B. MODELLING EXAMPLE SCAFFOLD MODEL

This example scaffold model is defined using the software *Grasshopper*, a plug-in for *Rhinoceros*, a popular digital modelling software among architectural designers. Steps for creating a digital model of a scaffold are described in this appendix.

## B.1 Shape

For this simple example, a rectangle is used for the initial shape. The *Rectangle 2Pt* node defines the shape. In order to have the center of the rectangle remain at the origin, a series of math operations are used as shown below to translate the width X and width Y *Number Sliders* into coordinate points.

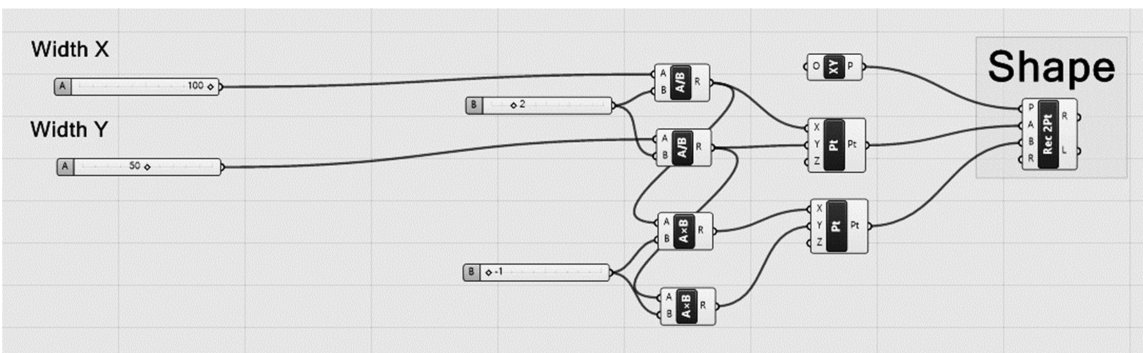



**Figure 143: Visual scripting definition – Shape**

## B.2 Grid

Again, because this is a simple example, a regular grid is used for the scaffold grid. Depicted in Figure 144, the shape is transformed in to a surface using the *Boundary*

*Surfaces* node. This surface is then used as the input for the *Grid Structure* node. This node is part of the *LunchBox* package of tools. Two more *Number Sliders* define the U and V inputs; these represent the number of divisions in the X and Y directions of the shape.

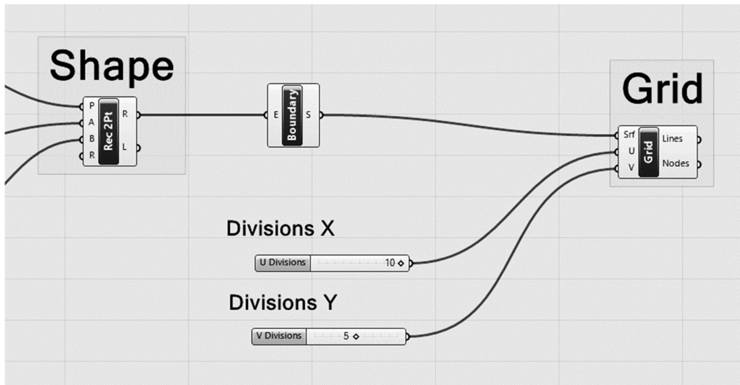



**Figure 144: Visual scripting definition – Grid**

## B.3 Levels

It is assumed, for this example, that each of the levels in the building are a copy of the lower level and the mass is an extrusion. A *Linear Array* node is connected to the shape surface. The *Direction* input is the Z direction and a *Number Slider* defines the distance, which in this case will represent the floor to floor height. The *Number* input is the number of floors, however we need to use an *Addition* operation to add one to this number. (The *Linear Array* counts the original geometry so we need to add one to this count to create a roof for the upper floor.)

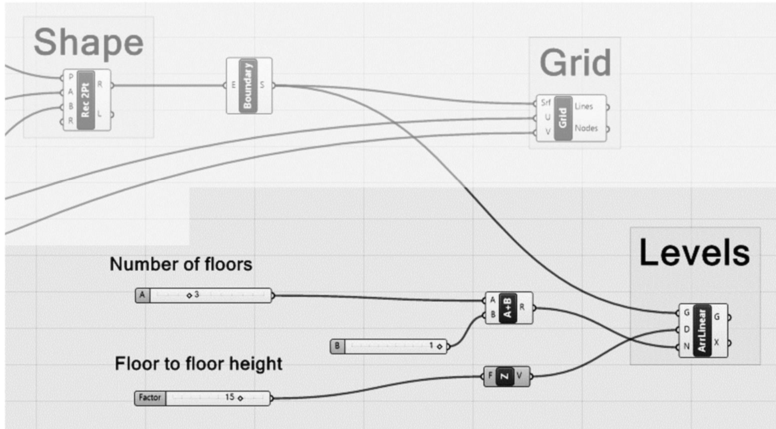



**Figure 145: Visual scripting definition – Levels**

## B.4 Initial surfaces

Defining the initial vertical surfaces uses the shape surface, an Extrude node, and the same *Number Sliders* that defined the levels. A *Multiply* operation translates the number of floors x floor to floor height to the initial building height.

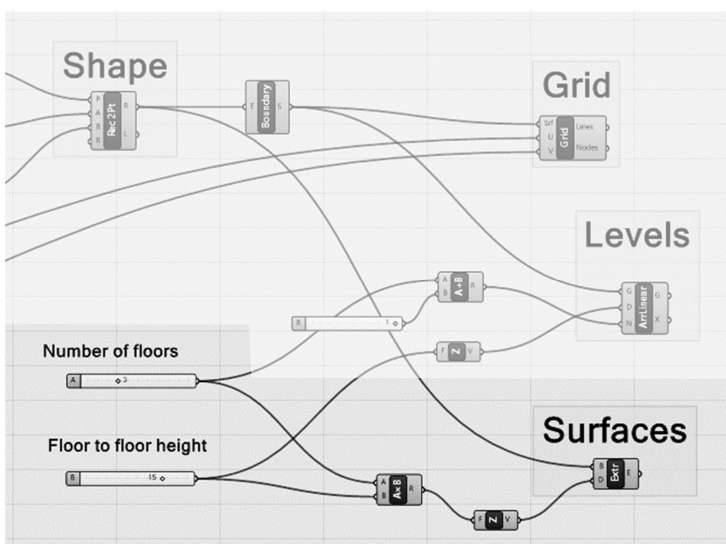



**Figure 146: Visual scripting definition – Initial surfaces**

## B.5 Edge of slabs

A revised set of arrayed floors levels is defined which creates an offset dimension between the structural grid and the edge of floor slab. The previously defined shape is *Offset,* made into a surface, and arrayed using the previously defined number of floors and floor to floor height.

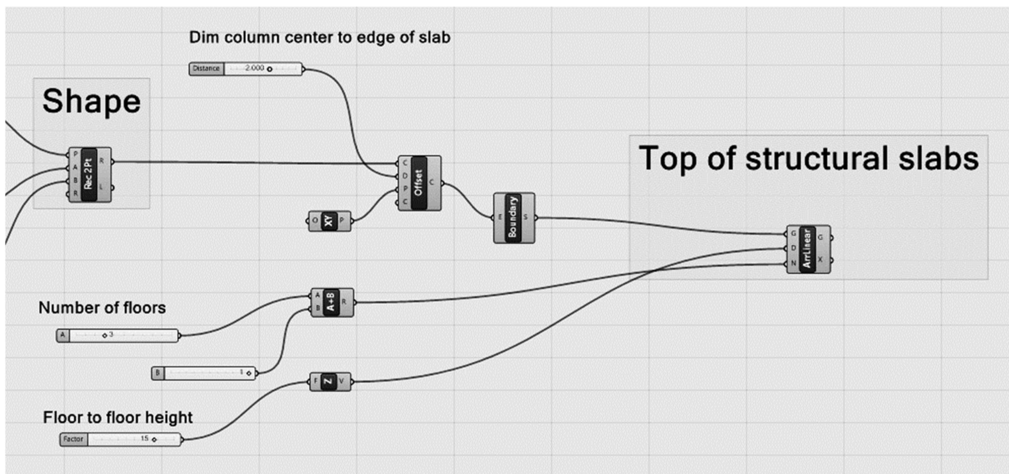



**Figure 147: Visual scripting definition – Edges of slabs**

## B.6 Offset surfaces

A revised set of uses three additional *Number Sliders*: one for the dimensions between the initial surfaces and these offset surfaces, one for the dimension between the top of the surfaces and the upper level, and one for the dimension between the bottom of the surfaces and the lower level. Similar to the above edge of slab definition, the initial shape surface is *Offset.* That offset shape is then given the ability to move in the Z direction. This defines the bottom of the offset surfaces. Similarly, the upper level offset shape is allowed to move in the Z direction. These two new lines are then *Lofted. Loft* creates a BREP (boundary representation), which can be exploded using *Deconstruct Brep* in order to select individual surfaces.

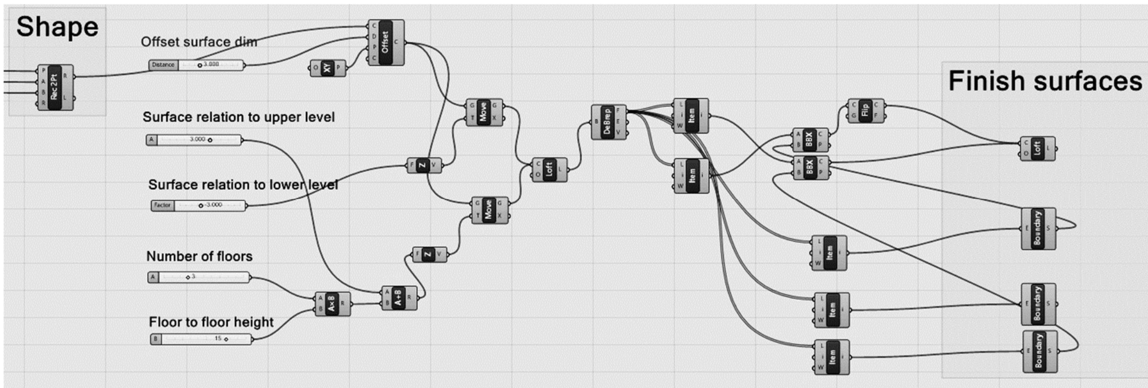



**Figure 148: Visual scripting definition – Offset surfaces**

# APPENDIX C. PRESENTATION TO AND CONVERSATION WITH FABRICATOR TRANSCRIPT

July 18, 2018, 10:00am EST

| | |
|---|---|
| Nathan Brooks: | Good morning, this is Nate. |
| Jeffrey Collins: | Hello, this is Jeff Collins. |
| NB: | Hi Jeff, how are you? |
| | We'll let everybody get on the call and then I'll introduce everybody that I asked to join. I asked a few others to join that work with this in and out every day on a very intimate basis. So, I figured they can answer more of your questions and more in depth and I could. |
| JC: | Great. I appreciate that. Thank you. |
| Robert Fisher: | While we're waiting, and maybe I missed this answer, I just got on the call; is *Grasshopper* the programming language…. |
| NB: | You cut out there. What was that Rob? |
| RF: | Does that refer to *Grasshopper* the programming language or *Grasshopper* the coding lessons software? |

NB: I believe that's the coding language.

RF: Okay. I just googled *Grasshopper* and came up with a whole bunch of different possibilities.

I've never used the *Grasshopper*. Y'all will have to explain more of the term, but it's also detailing software, isn't it?

JC: It could be. It's in some ways similar to *Dynamo*, but it is a plugin for *Rhinoceros*.

RF: So that's where remember seeing it.

JC: I actually teach students in the Undergraduate program here at Georgia Tech how to make parametric models using *Grasshopper*.

RF: With *Rhino*?

JC: Yes, you can make the visual programming descriptions similar to how *Dynamo* does with the nodes and those funny links between them - if you're familiar with *Dynamo* at all - and then you can put those models directly into *Rhinoceros.*

NB: So, is *Grasshopper* a visual version of python like *Dynamo* is?

JC: Exactly. Yes, all the nodes have a python script behind the scenes. Yes.

RF: You mentioned you teach *Grasshopper* and I hear you talking about *Dynamo*, so obviously you know what it is. Do you teach *Dynamo* classes as well?

JC: I don't. I don't teach *Revit*. There's another instructor here that teaches *Revit* and I'm not sure if they get into *Dynamo* at all in that course.

I think that, in terms of being at a design school and thinking from that perspective we're more inclined to go with *Rhino* and *Grasshopper* because it has, at least, the allure that it’s more of a designer's tool as opposed to a *Revit* kind of thinking which is geared towards construction documents and fabrication and that end of the spectrum. All that I say when I put my teaching hat on. I'm also an architect, so I’ve dealt with both ends. And part of what my research is to do is to link both of those together. How can we find a way that fabricators and architects [working] together using a digital model can go back and forth on that kind of spectrum?

NB: Okay.

So, you and Mo set this meeting up asked me to join, so I asked a couple of our folks. Tony DiBella is obviously here. He has been since the beginning. We also have Sam Taylor and Gene Hicks from our Oxford Plant and Rob Fisher joining us.

Rob’s been working with a little bit with *Rhino* and Tony, I don't know how much you've jumped in on it with the 3D printing project that we had. But, Sam and Dean down in Oxford, they have been heading up our *Dynamo* initiative and Sam is by far heads above everybody else in our company for *Dynamo*.

So, a little bit of a knowledge about each one that I thought we’d bring. I guess I really didn't get a whole lot of information about what we could add. If you want tell us what you're looking for and then we'll fill in the blanks?

JC: Sure. I sort of gave a preview of what I'm trying to do, [which] is to link these two descriptions, from the design perspective of the overall building and these details that you all are very intimately aware of and how do we actually use the digital model to communicate with each other better. I'm trying to set up - I'm calling it a framework - for coordination. I know that part of your workflow is remodeling everything that you would need to fabricate. And my big picture idea for me is; how do we go about breaking that down? I know there's lots of contractual issues, but that aside, how do we actually make the digital models work for both teams, the design team and the construction team, more effectively and more directly. So, I guess all that is to say that I'm looking for feedback on where

I am in my research. Do you all have the ability to look at the screen if I share some images?

NB: Yes, absolutely. I'm going to turn the screen over to you. Okay, it should be all yours now.

JC: Okay. Does everyone see a PowerPoint?

NB: Yes.

JC: Okay, great.

So, I know there's a whole bunch of slides in here. I just threw in everything I have together and we don't necessarily need to go through all of them and a lot of the slides go through pretty quickly just to give a kind of sense of the breadth… of the work that I'm trying to bring together.

So, this is a sort of what I was just talking about. Actually, these diagrams came from was a project that I did with Mo at his previous operation [Shands] where on the left we have the design intent model and on the right we have the model that I helped them to create in *Revit* and using parametric modelling. I was really struck by the difference between these two ways of thinking and how long it took to remodel the whole thing.

So that became the inspiration for this whole project, really.

And then this whole series [of slides] is talking about this disconnect between the designer and [the] fabricator point of view. And my big research question is: how we can actually link these together to, as I said before, have the model more directly be exchanged between them but also to enable further design exploration, further fabrication detail incorporation, [and] in the design phase? And I know that Mo and a lot of you are already involved with design assist and I think this is piggybacking on that or enabling that process even further.

This is [the] five sections of this presentation. I can go through this first section pretty quickly; I'm kind of preaching to the choir about how useful this kind of way of thinking would be. But part of the work that I've done is going through a lot of the background of precast and how designers have expressed their intent to contractors over the years and how, obviously, making a digital model will be much more effective.

So, I've looked at lots of… examples tried to make digital models to [understand] both the patterns that designers and fabricators are interested in and also the details of those pieces. This is another view of that project I showed in the beginning [Shands] where we modeled all these pieces and a lot of that was for a coordination, as you all know.

I want to add onto this [Perot Museum] with some background and more information on Perot that I'm sure you all are much more experts on firsthand. That would be a really interesting project, I think, to add some more information about how you all went about modelling from your perspective.

NB: Tony could answer that probably better than any of us.

TD: Yeah, I know that project pretty well.

RF: Tony was our lead designer on the Perot project and can answer whatever questions you may have as far as the forming in that whole process.

JC: Ok great.

NB: Not to derail the conversation, but, I think, I'm looking at your slides and reading through and we're running through these and, I think, in my opinion, let's answer as much as we can today, but if you will send us these slides, and we can answer some of the questions that you have in the slides, and I think it would be interesting to get… I'll gather all the feedback from our different folks here at Gate and then we'll send you all of that all at once. If you have need some information on Perot, get directly with Tony and ask him those questions, please copy me on it. He can answer, no reason for me to be a monkey in the middle on that.

JC: I’m happy to do all of that. And thank you.

NB: And then we can follow up with another conference call but just continue to go through these slides so we get the idea of what you're looking for here.

I think that would be a good way to go about it. That gets you some good answers and we can follow up with however much help you need because you are right about the subject of not having to redo the model and not having to redo everything. It's a huge amount of work. It would save us time and make project timelines go so much faster.

JC: Perfect. Absolutely. Let's do it. I'm very interested in Perot and getting some more feedback on all of this, but I do have in a few more slides some really specific questions. Please comment on any of these slides, but I've tried to make more specific questions as well.

So, the next series, some people refer to it as the top down perspective; the big picture of what's happening on the overall façade. I’ve looked at a lot of precedent buildings and gathered different patterns that I will show. The big idea is this; that we can make this what I'm calling a scaffold model and that can define key features in the building and actually does a lot of the work of defining the panel boundaries for the project.

This simple example of this rectangular scaffold [to which] we can apply a grid that could possibly be the structural grid, array that to levels, define the surfaces, and all that data comes together and can define the panels. Obviously, there are some times where it doesn't work that directly, but that's the basic idea. Then, enhancing that a little bit, we can offset the slab edges away from that structural grid, offset the surface even further from that, and allow the top and bottom to extend beyond the slabs. So, this is trying to get it to be a little bit more realistic of a scaffold for the building and then we can look at what the implications of that are. Looking back to a kind of projecting the structural system to the façade or transposing those dimensions to the façade and all of these have different implications. And it can also be that the façade panelization has seemingly nothing to do with the structural system and I will go through more examples of that.

These are just kind of breaking the rules that I’ve set up a little bit; it doesn't necessarily have to be vertical columns, and it doesn't necessarily have to be a rectangular building, and as I mentioned, it doesn't have to have a grid for the pattern.

I've looked at a lot of different buildings. Hopefully some of them are familiar to you. There are contemporary ones and historical ones. I’ve looked at obviously way more than this, this is just to give an idea. Then, as I said, looking at what the actual patterns are. So, trying to define what those patterns are and what are the variables that control those patterns? And, by the way, all of these pink models are generated in the *Grasshopper* tool that we started to talk about it in the beginning.

There are regular grids, irregular grids, running bond patterns, vertical, irregular patterns, different kinds of diagonals. Then, looking at the precedent buildings, there's also a phenomenon where you could have different kinds of patterns on a surface. Those are what I'm calling regions and in each of these different colored areas, we can apply different patterns, or as shown on the right side, it could be that the pink is precast and where there's not any material it could be a different material, glazing or metal panels. So, it’s is way of actually composing materials on the façade.

So, that's the designer big picture kind of view. Then how do we jump all the way over to the other end of the spectrum and look at the panels from the fabricator point of view? And this is the list of really specific examples or questions that I'd like to talk to you further about or you can, as you suggested, get back to me with some of these or we can have a follow-up conversation. But the big idea is how do you all go about defining what the panel variations are on the façade? Are their specific dimensions of panels? [Do you have] rules of thumb that you're keeping in mind? And, anything more than just the geometry. Mo and I have talked about [how] you can constrain these models that I'm going to show you of the panels in certain ways but it's not really necessarily a dimensional problem because it might be there's a lot of things you are balancing with all these features that can be on the panels.

So, this is how I'm organizing the kinds of models that we have; this whole list of parameters that can change each of the models at the panel level, and that's an abstraction of what is on the right, which is the *Revit* family model. We can adjust this… set of parameters and it changes the geometry. So, it's not remodeling once you have these family types, and I'm sure you all are familiar with this kind of modelling process. And just like the façade patterns, I looked at those precedents to get family types and tried to define, again, types of panels and also all of the variables that control them. So, we can have rectangular flat panels, non-rectangular. We can add openings. And as you can see on the bottom here, it adds... variables depending on what kind of features you have and how they're controlled and how they're modeled.

And then what is really interesting is when you can start to combine [features]. So, looking at all of these buildings I've seen this phenomenon of the facet and opening, which happens a lot. We can link those that geometry together and have them be controlled by the same parameter.

And, obviously, this is what I was talking about. You all can tell me; the kinds of limits of these dimensions. Right now, I can make a panel any size I want. We can make the opening go all the way to the edges and things like that. But that's not necessarily constructible. So, you all can tell me the limits on that.

NB: Well, that’s going to be something that’s very, very hard to define. It varies so much by plant, by location, by how thick the panels are… and obviously [the] size of the job we’re working on… And Tony and Rob are very familiar with the job that... we looked at [Perot] and initially set it this way and then a couple of small things changed in the design of the structure. And now the panel is no longer [the same]. We had to make them two inches thicker or wider or moved the profiles to adjust this and each one of our plants and every precast manufacturer has a different capacity. So, let’s take, for example, our Kentucky plant can only… the biggest panel width-wise they can produce and be stressed for something like this would be like a 12/11 and a quarter. And then another one of our plants can do 16 feet wide. So, what we know, we can give you some parameters, some general parameters. Shipping typically rules the roost and what can you get up the ns? You have to meet shipping requirements and get underneath these bridges, that's a big thing. So, we can go to that. But as far as being able to say, you know, you can take a window this close to an edge or you're able to make a panel this thick in this area, I'm not sure that we're going to be able to get good parameters to you for that, but we can definitely get you something.

JC: Yeah, and that's something that I've realized in doing these models and why I'm shifting away from trying to constrain the models and, rather, have the models available to have a conversation amongst designers and fabricators together because we're never going to be able to make the model and constrain it in the right way because of this kind of balance of all these features that you're describing.

And along with that, as I said, I'm a designer so I know our way of thinking; as soon as you say I can't do something, I want to do that. I see that there's a limit that's [been] put on me, I'm going to try to figure out how to break it. So, it's not really useful for either side of this conversation to have a model that is too limited.

NB: Yes. I agree.

JC: Rather, [we could] have a model that can enable that conversation.

NB: Okay. I like it.

JC: Alright. So, I've looked at these models, there's lots of different ones. We would never define all of the different features, but some of them get pretty interesting about the way that their modelling scripting operates.

RF: And you have these written into parameters? You showed a slide earlier had a *Revit* family and I recognized the parameters there, but do you have these in a script or are these just parameters you need to go into the *Revit* model and change a few parameters and it goes across the border. How do you manipulate?

JC: Yeah, so take this tapered one for example. This is directly in that list of parameters in *Revit*. So, you can just go in and change the taper bottom dimension - I'm talking about this one on the left here - to be a foot and it will slope that geometry automatically more. So, the real answer is going to be a combination of those things, the script and the direct modelling. These ones [relief patterns], this one in particular, the middle one and the one on the right, those patterns that are applied to the panel are done in *Dynamo*. That's the way that I've modeled it currently. There is a way to make the controls in *Dynamo*, [and then code them to be] a parameter directly in the interface of a *Revit*. And we can do that. But that's not how I have it set up currently.

NB: We're trying to learn more about *Dynamo*. So, if there’s anything you can share, any programs or any *Dynamo* scripts you have written and you're willing to share, we would love to see those to learn from them.

JC: Okay, great. Yeah, I'm happy to share the ones that I've made for this presentation and we can make a drop box for all of this to share.

NB: Alright, wonderful. Thank you.

JC: This one [relief + opening] actually is looks like it would be scripted, but it's not. This one is [perforated pattern]. So, just to get through these panels, there's obviously lots of them and just to note this one; this idea is that sometimes - what I'm calling this gesture - the features of a panel bleed over to the panel next to it. And I'll talk about that a little bit more, how I've modeled another project, in a few slides.

So, how am I going about getting these things to talk to each other? There's two approaches, [those are] direct and indirect. And then each of those have two examples that I'll show. The first is under the direct, [where] we can go directly from that scaffold that I talked about in the beginning to a panel. This is that scaffold, if you recall that, we can go in and individually select or isolate individual panels or panel boundaries, get the data from that [panel] – which is the size of that piece of the building and the coordinates for its location. And then I read it - I'm reading that data through *Dynamo* - and then apply a *Revit* family, a predefined *Revit* family, to it. Then all of those parameters that I defined for this panel are still… we can still define those. So, while the scaffold is defining the length and width of the panel, we can still adjust the thickness of the panel and the window size and location. We can do that iteratively across the building and get all the panels attached to the scaffold.

And then there's the opposite direction. How can we go from the panel to the scaffold? So, recalling all these of different surface patterns, we can go through this scaffold to panel process and I really just want to get you to notice this non-rectangular piece that's down here on the right. We can actually start with that panel or start with a slightly more interesting one that has the facet opening and we can define the boundary for that panel and get the data about that boundary and further information about all of the features. This list it should say the facet dimensions and the window dimensions and all of that, and then bring that back to the scaffold and have that defined the scaffold for us based on those boundaries. And we can do that with all kinds of different patterns.

RF: Jeffrey, I saw your parameters for panel joint. Do you take into account the gap between structure and a back of a precast panel? Is that also a parameter that you can adjust?

JC: It should be. In the beginning when I was talking about how to set up the scaffold, there's a dimension from either from structural grid to the back side of the surface or from the edge of slab to the backside of the surface.

RF: That's a function of the scaffold.

JC: Yes, currently. And I know there will be some panels where the back side is not always flat as well. So, [then it] becomes a question of what you're actually dimensioning there and where that surface exists. Does that make sense?

RF: Yes, and it is usually the first thing that we start negotiating with designers about when we start talking about fabricating fancy precast; we need a flat surface on the back really to be able to fabricate it and we need a two-inch air gap to maintain PCI standards. It's just something that doesn't seem to have been communicated very well in the design community.

JC: No, I've never heard of that dimension. That's great [to know]. That's between any structural member and any piece of the precast?

RF: As a rule of thumb, we want two inches between precast and structure and we want three quarters of an inch from precast to precast. That can vary, but three-quarter inch joints and two-inch air gaps is usually the first thing that we have to correct on an architectural model.

JC: That's good. That's good. Great data. I don't think we would ever draw anything that large. We draw one line.

Okay. So, I'm going to the more the indirect scripts between the panels and the building scaffold diagram. I'm again looking to the precedent buildings. There's lots of these. I'm just showing this one as an example where, as in this building [Roundhouse] as it's being constructed in the background here, I would make the scaffold three individual panels across the height. But, obviously, we can see that that entire vertical strip was made as one piece. So, how do we actually deal with that kind of conflicting data where the panelization is saying a different thing than the pattern.

So, this is [the way that I'm] of diagramming that right now; we can start with the building surface and we can, as the scaffold, we can still define the panel boundaries that we like across that surface. And I'm offsetting these just as the graphic. Then we can have another layer which is all that a panel data about, in this case, the facets and the locations of the windows. And then another layer of how the panelization actually happens. So, we can see the difference between the three-panel tall and the one panel for the vertical of the whole building. And then we can state to project all of that data back to the building surface; so we can give a thickness, project back the window locations, the façade openings. And then - I wish it showed a little bit darker - but this actually split those panels vertically to be [similar to] the picture of the construction [which] showed the entire height of that surface. So that's the idea that the panelization and the pattern might be slightly different.

And then there's this other phenomenon where - and this is what I was going to referring to about that gesture that goes across multiple panels - we can have a pattern that goes across lots of panels and this is an example of that that I've been looking at. I know Gates or sorry, Perot, has a lot of this as well. So, we can again start with that building surface. In this case, we're actually defining the panelization first because that's part the graphic of the façade. And then there's this pattern which is that texture that goes across. I'll show that building again if you're not familiar. So, there's this kind of layers where you have the joints between panels, this textured piece that goes across those joints, and then this seemingly random pattern of the windows.

So, we get the joints and then this texture. I'm making that through this staggered quad pattern and then defining just these blue regions that will have that pattern applied. And then the randomly located windows. And again, projecting all that back to the surface, this time the windows first, and then that textured pattern, and then slicing it into those panels. And that's how I'm, at least for this example, looking at kind of patterns across panels.

And then, something that I'm also keen to get your feedback on. This past semester, there was a studio in the school of Architecture here that are designed a precast building and I shadowed what their discussions and then in the end did some interviews with them and collected their documents and then made a similar kind of scaffold process of their projects and also defining the panels that they were looking at. And this was a previous example that have, this diagram that I was looking at how to represent just a chunk of the building that's a two by two - two floor by two bay - piece of the building. How do we start to represent what's going on across the whole façade in this kind of little diagram? So, I did that with these three different projects that the students came up with. And this was an idea that, as I said, I'd like your feedback; could I actually put these…. scheme through that same process and do a test of this design assist with the digital models using these three case studies?

NB: And is that twisted panel castable in concrete?

JC: Well, that's a great question. I just kind of accepted what they wanted to do, [but] documenting how that kind of design assist negotiation and conversation with you all would be interesting to me if that is something that will also be useful to you as a study of learning different ways of modelling that

NB: I'm asking. Is it castable? Anybody?

RF: Sorry, I was sitting here talking away and I was muted. Sorry about that. To answer your question about [whether this is] castable; somewhat of a twist, yes. The twist is shown here, that would be pretty… you'll be flipping over from a front side and rear side. That would have to be a very small to handle that you could react to something like that vertical. But all those kinds of things, do's and don'ts… Jeffrey, I think it would be very, very beneficial if you could make a visit to one or more of our plants, talk with our folks in person and get these things. When you have these. What you're doing I think is going to help the entire precast and architectural community to start to open up the lines of communication because I want you to feel like if you have a question can we do this, you can pick up the phone and you can call us. As far as the constructability list, you know, we would have to go through some design assist and talk about some of the do's and don'ts here for this exact slide. The other two that you had there, I didn't see anything with that; those are very interesting pieces, but there's nothing there that we couldn't predict.

NB: I'm asking based on some things that we ran into that were not castable as they were designed on Domino, just some little corner pieces. Once you put yourself into the hands in the shoes of the person building the mold and I don't know how a wood worker would make that shape.

RF: A wood worker wouldn’t make that shape. That would be a 3D, CNC something like that.

NB: But no, I think getting these slides and having your questions here and what I'll do, if you'll send them to me, I'll forward this on to all of our folks. What I'll do is I'll take your questions out of your presentation, put them into a document to send out to our guys and let them answer that in the document and then send them the slides as well and then we can look through all of this all at once. Let's get some different answers back to you. I think keeping the lines of communication open. I think following up with another conference call or go-to-meeting, like we're having to walk through our answers, talk a little more, but then also figuring out how we're going to open up the lines of communication, like you said, between design assist and what we're doing right now is key.

JC: Great. Thank you very much.

NB: What other questions can we answer for you today?

JC: I think that that's all I have for today. I would love to schedule a visit. Shall I through Mo when I get back in touch with him or what do you all suggest?

NB: You are there at Georgia Tech so the Monroeville plant would be very easy to get to. How far are you away… well the Jacksonville plant is more structural.

I don't know how far you are from Monroeville Alabama, but that'd be a really good plan to visit.

You get back with Mo. He can coordinate with the plant operations folks and you know, set up things and then possibly even get a couple of plants set up over a couple day tour. I don't know how much Mo's talk to you and you know, the guys, you kind of mentioned that a little bit, but some of these new designs are requiring us as precasters to think not only think outside the box but blow the box up and go to a completely different way of thinking. And we're looking at different ways to create our molds, 3D printing, CNC, different things like that. We're doing that in two of our plants right now, so you're welcome to come up and look at those different things as well.

JC: Yeah, that'd be great. In a way I think because we have these tools, we can make more expressive forms more easily. But that doesn't mean that they're buildable. And it's great when you all are from the fabrication side are also interested in exploring those possibilities as well and adapting based on those new [opportunities].

NB: Yeah, the production ears of me says, no way, we're not doing that, that's dangerous. We're not even going to touch that. But the R and D side of me says, no let’s explore it. You design it, let us look at it. And then we can tell you the parameters from there, from what you want, what we have to a step back a little bit from and what we can take out there a little further.

JC: Yeah, that's true because [for example] in the twisted piece, if we knew say that we couldn't go over eight-foot-tall, having that knowledge might actually take this design in a different way. But you could also say something that would spark an interest and we would never have thought of doing a design in a certain way that because of this conversation that we had… that emerges as an idea.

NB: Well, you're going to have push us if it’s up to us we’ll do flat pieces all day long with a reveal right down the middle of them and send them all to you nice and simple.

JC: Okay, we’ll push you.

RF: And that's what we like and that’s what easy to do. But we also enjoy this R and D and this much more difficult stuff. But, yeah, I've got some thoughts and I'll email you it. Just so we know on like that twisted pieces, kind of document what I know about those because we have done a little bit of that and about what angle you can go it, and what parameters we had to stick with, what worked and what didn't.

JC: Well, excellent.

NB: It's nice to be asked these questions by an architect. I don't know if that's ever happened to me anyway. Honestly, it’s flattering.

JC: Well, no, it makes so much sense. And you know, I mentioned the contractual issues that I think are preventing this, how do we make our work together, maybe make a change in those... I don't know, but that's slightly different... that's an asterix on this work.

RF: You have a - you obviously know this - but it's a difficult road you're going down here because you're changing the way people think because right now it’s the building is designed and its handed off say here's what we designed, we’re done with it, try to make this work and tell us what can't work. We're looking and you’re looking to change that culture [to] let's work from the very beginning with the same model and make this work so we're not having to redraw what you already did.

JC: Right, exactly.

NB: That’s the same way that we want to see the industry go.

If you’ll go ahead and make a drop box and send us a link to it, we’ll go in there and anything that you could share with us, we'll be happy and we’ll share whatever we can with you.

JC: Excellent.

NB: And then give us a week or two here, a couple of weeks, I'll be out for a couple of weeks, but give us a couple of weeks to gather everything back up and get back to you. Is there a timeframe that you need all this?

JC: Oh, yes; [jokingly] last month.

NB: Well that sounds about normal.

JC: No, I appreciate time and thought that you all put into it and a couple of weeks sounds perfect.

NB: Okay, if you'll send us the information, send us the link so we can get it over to all these guys and we'll start getting some feedback.

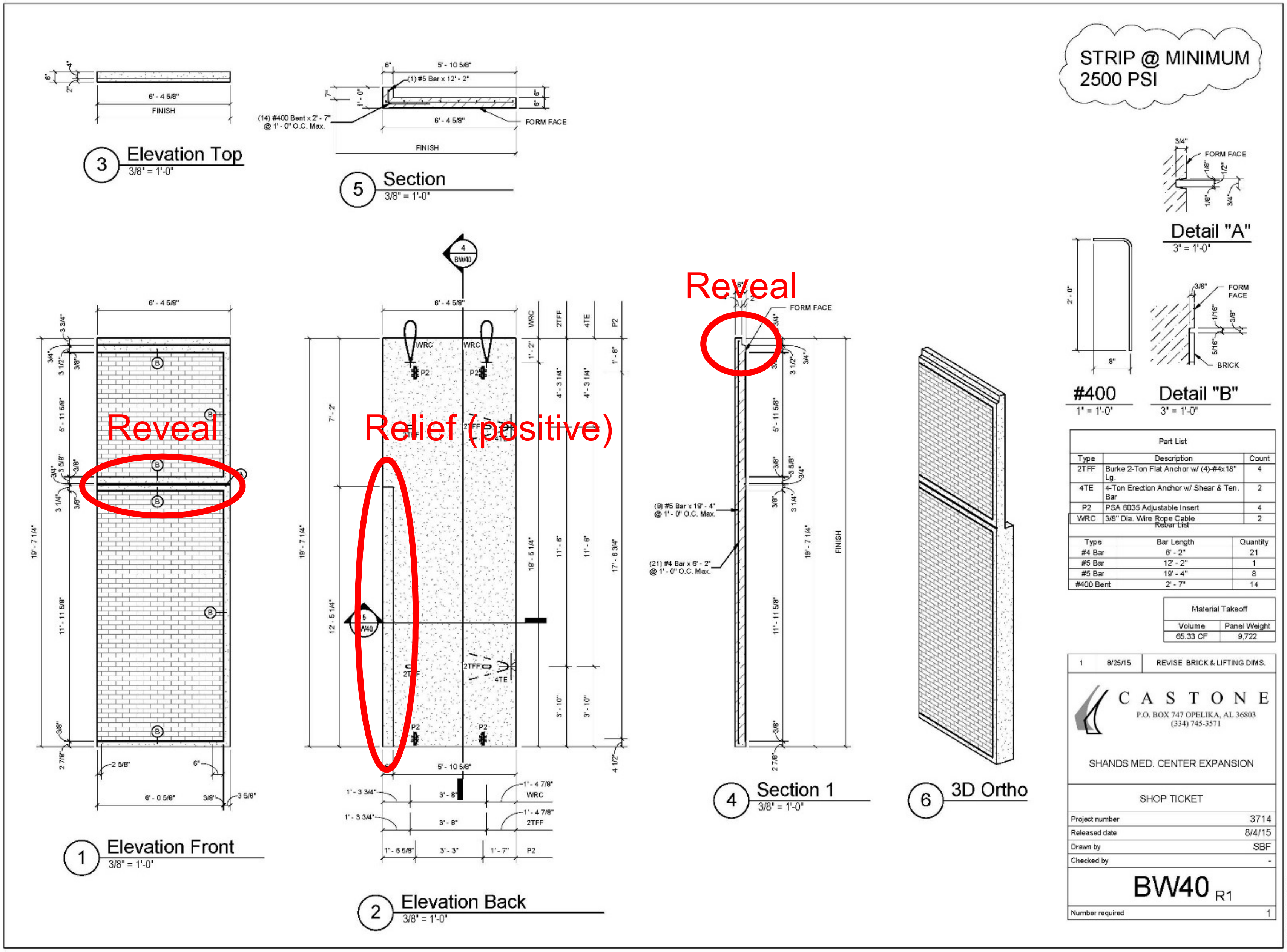
JC: Thank you all very much. I really appreciate it. Look forward to talk to you all soon.

NB: Sometime mid-August.

JC: Excellent. Alright, talk to you all soon. Have a good one.

# APPENDIX D. ANNOTATED EXAMPLE SHOP TICKETS

A sample of shop tickets from University of Florida Health Shands Cancer Hospital (designed by Flad Architects, precast fabricated by Castone Corporation) with panel features which a design intent model may not include – such as holes notches, reliefs, and reveals between panels, among others – are highlighted and annotated on the following pages.




Part List

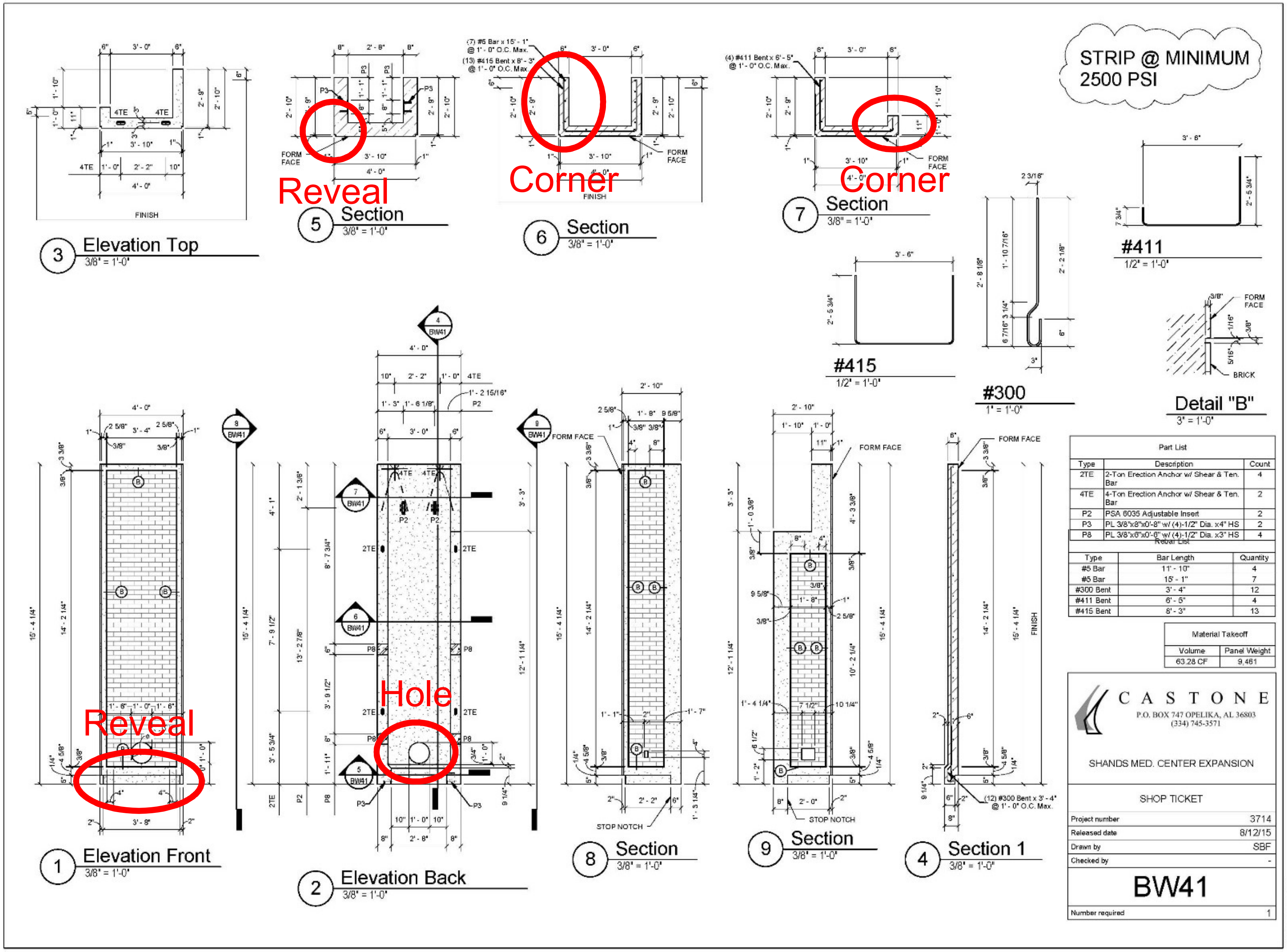
| Type | Description | Count |
|---|---|---|
| 2TFF | Burke 2-Ton Flat Anchor w/ (4)-#4x18" Lg. | 4 |
| 4TE | 4-Ton Erection Anchor w/ Shear & Ten. Bar | 2 |
| P2 | PSA 6035 Adjustable Insert | 4 |
| WRC | 3/8" Dia. Wire Rope Cable | 2 |

Rebar List

| Type | Bar Length | Quantity |
|---|---|---|
| #4 Bar | 6' - 2" | 21 |
| #5 Bar | 12' - 2" | 1 |
| #5 Bar | 19' - 4" | 8 |
| #400 Bent | 2' - 7" | 14 |

Material Takeoff

| Volume | Panel Weight |
|---|---|
| 65.33 CF | 9,722 |




| Part List | | |
|---|---|---|
| Type | Description | Count |
| 2TE | 2-Ton Erection Anchor w/ Shear & Ten. Bar | 4 |
| 4TE | 4-Ton Erection Anchor w/ Shear & Ten. Bar | 2 |
| P2 | PSA 6035 Adjustable Insert | 2 |
| P3 | PL 3/8"x8"x0'-8" w/ (4)-1/2" Dia. x4" HS | 2 |
| P8 | PL 3/8"x6"x0'-6" w/ (4)-1/2" Dia. x3" HS | 4 |

| Rebar List | | |
|---|---|---|
| Type | Bar Length | Quantity |
| #5 Bar | 11' - 10" | 4 |
| #5 Bar | 15' - 1" | 7 |
| #300 Bent | 3' - 4" | 12 |
| #411 Bent | 6' - 5" | 4 |
| #415 Bent | 8' - 3" | 13 |

| Material Takeoff | |
|---|---|
| Volume | Panel Weight |
| 63.28 CF | 9,461 |

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SHANDS MED. CENTER EXPANSION

SHOP TICKET

| | |
|---|---|
| Project number | 3714 |
| Released date | 8/12/15 |
| Drawn by | SBF |
| Checked by | - |

**BW41**

| | |
|---|---|
| Number required | 1 |

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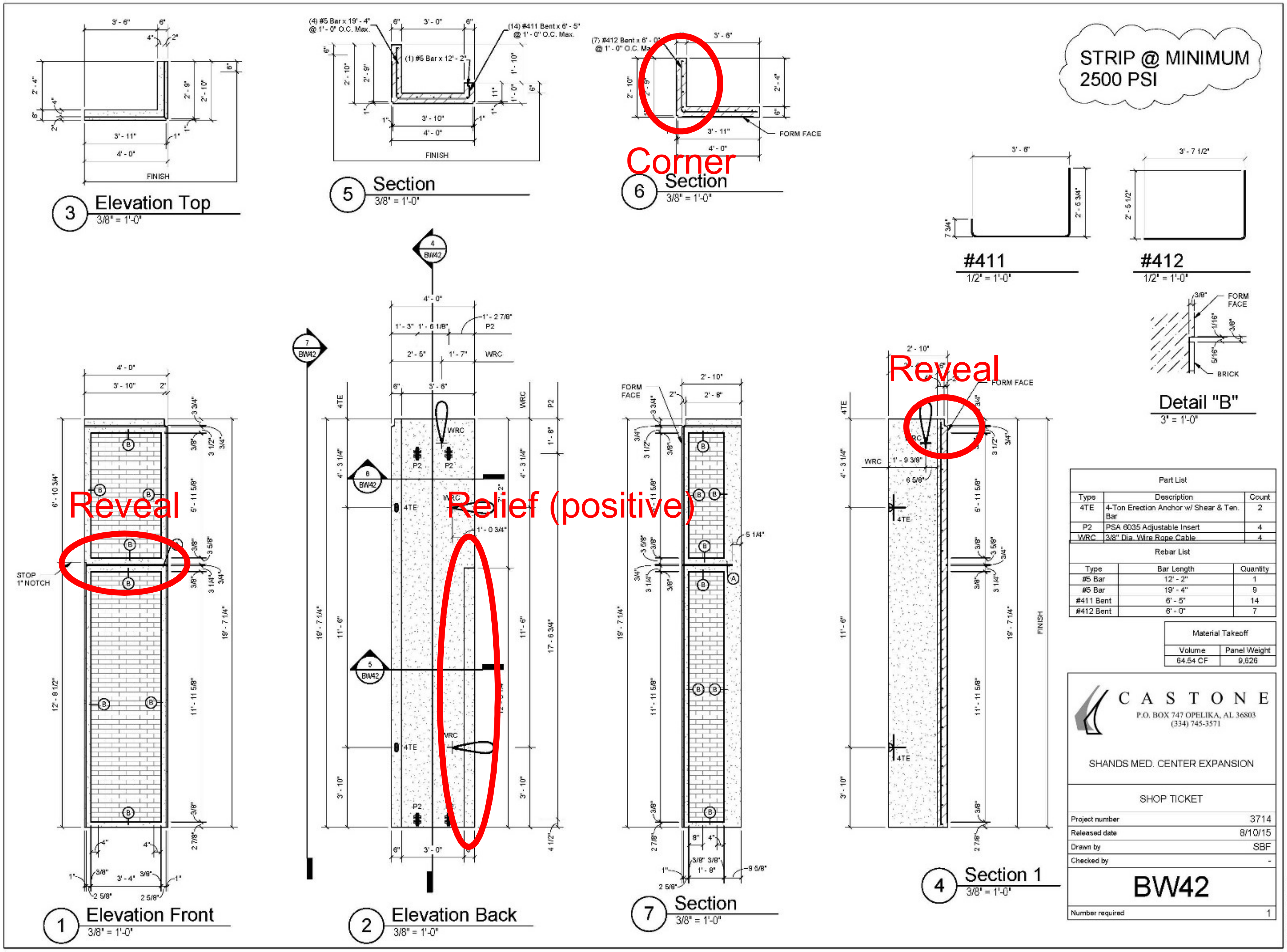


| Part List | | |
|---|---|---|
| Type | Description | Count |
| 4TE | 4-Ton Erection Anchor w/ Shear & Ten. Bar | 2 |
| P2 | PSA 6035 Adjustable Insert | 4 |
| WRC | 3/8" Dia. Wire Rope Cable | 4 |

| Rebar List | | |
|---|---|---|
| Type | Bar Length | Quantity |
| #5 Bar | 12' - 2" | 1 |
| #5 Bar | 19' - 4" | 9 |
| #411 Bent | 6' - 5" | 14 |
| #412 Bent | 6' - 0" | 7 |

| Material Takeoff | |
|---|---|
| Volume | Panel Weight |
| 64.54 CF | 9,626 |

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SHOP TICKET

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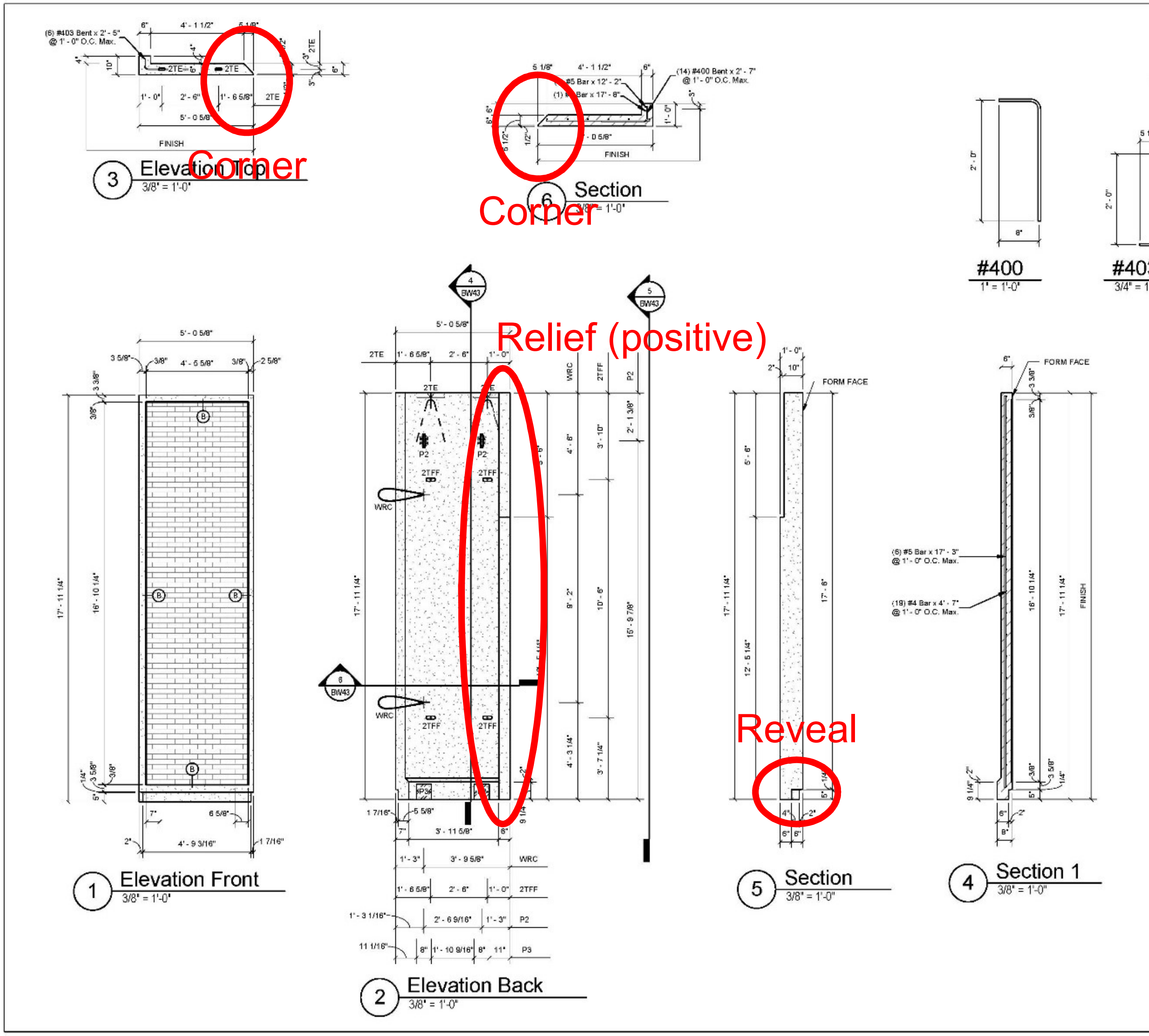
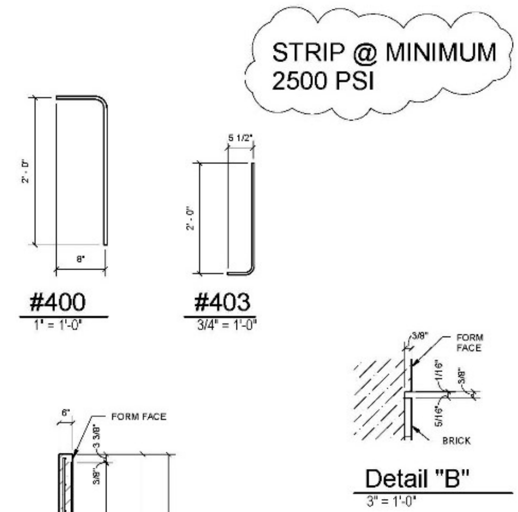
| Project number | 3714 |
| Released date | 8/10/15 |
| Drawn by | SBF |
| Checked by | - |

BW42

| | |
|---|---|
| Number required | 1 |




Part List

| Type | Description | Count |
|---|---|---|
| 2TE | 2-Ton Erection Anchor w/ Shear & Ten. Bar | 2 |
| 2TFF | Burke 2-Ton Flat Anchor w/ (4)-#4x18" Lg. | 4 |
| P2 | PSA 6035 Adjustable Insert | 2 |
| P3 | PL 3/8"x8"x0'-8" w/ (4)-1/2" Dia. x4" HS | 2 |
| WRC | 3/8" Dia. Wire Rope Cable | 2 |

Rebar List

| Type | Bar Length | Quantity |
|---|---|---|
| #4 Bar | 4' - 7" | 19 |
| #5 Bar | 12' - 2" | 1 |
| #5 Bar | 17' - 3" | 6 |
| #5 Bar | 17' - 8" | 1 |
| #400 Bent | 2' - 7" | 14 |
| #403 Bent | 2' - 5" | 6 |

Material Takeoff

| Volume | Panel Weight |
|---|---|
| 47.80 CF | 7,128 |

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SHOP TICKET

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|---|---|
| Project number | 3714 |
| Released date | 8/7/15 |
| Drawn by | SBF |
| Checked by | - |

BW43

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|---|---|
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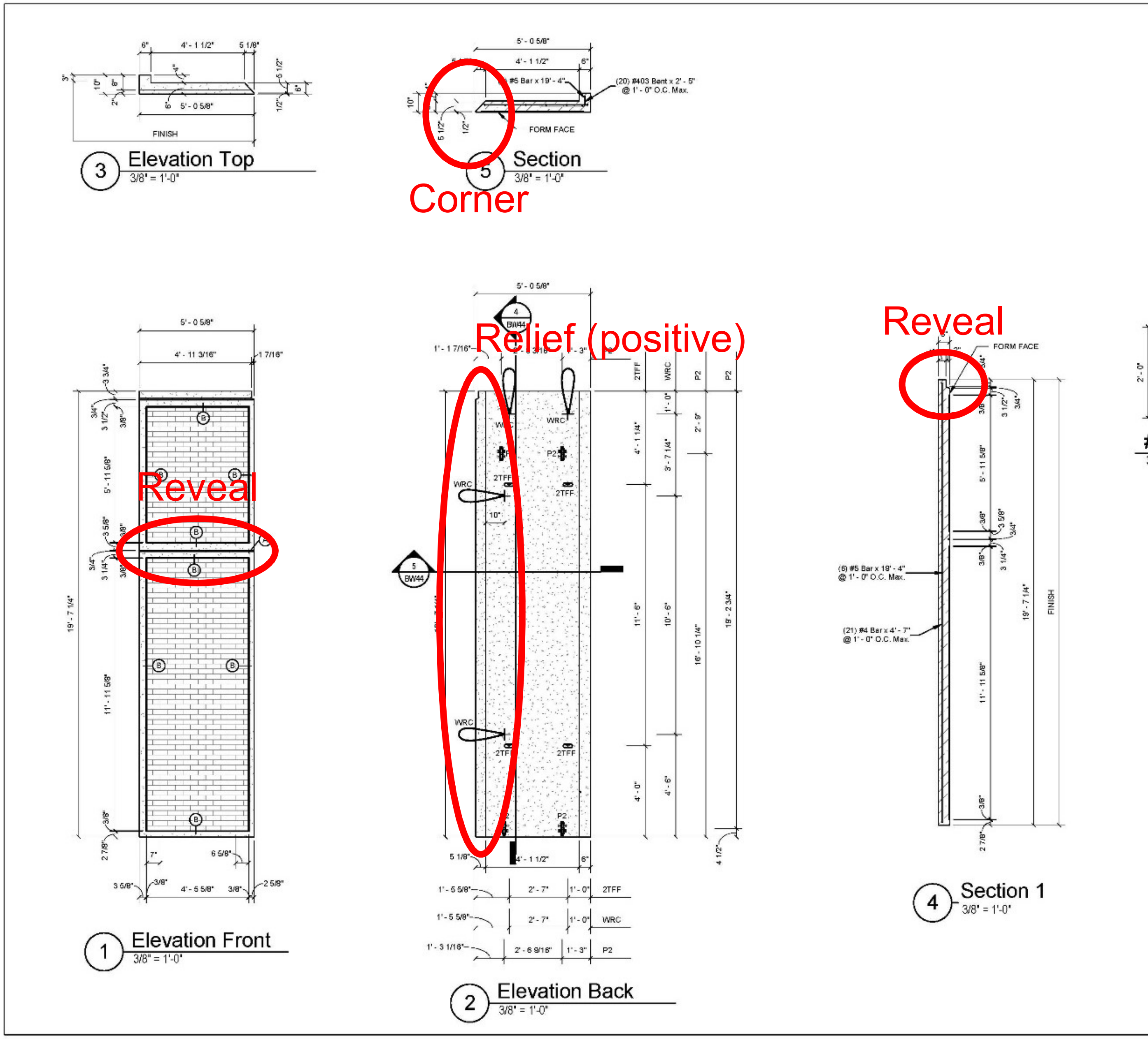


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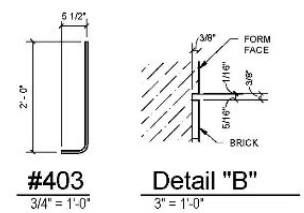


| Part List | | |
|---|---|---|
| Type | Description | Count |
| 2TFF | Burke 2-Ton Flat Anchor w/ (4)-#4x18" Lg. | 4 |
| P2 | PSA 6035 Adjustable Insert | 4 |
| WRC | 3/8" Dia. Wire Rope Cable | 4 |

| Rebar List | | |
|---|---|---|
| Type | Bar Length | Quantity |
| #4 Bar | 4' - 7" | 21 |
| #5 Bar | 19' - 4" | 7 |
| #403 Bent | 2' - 5" | 20 |

| Material Takeoff | |
|---|---|
| Volume | Panel Weight |
| 50.54 CF | 7,525 |

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SHOP TICKET

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|---|---|
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| Released date | 8/7/15 |
| Drawn by | SBF |
| Checked by | - |

BW44

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|---|---|
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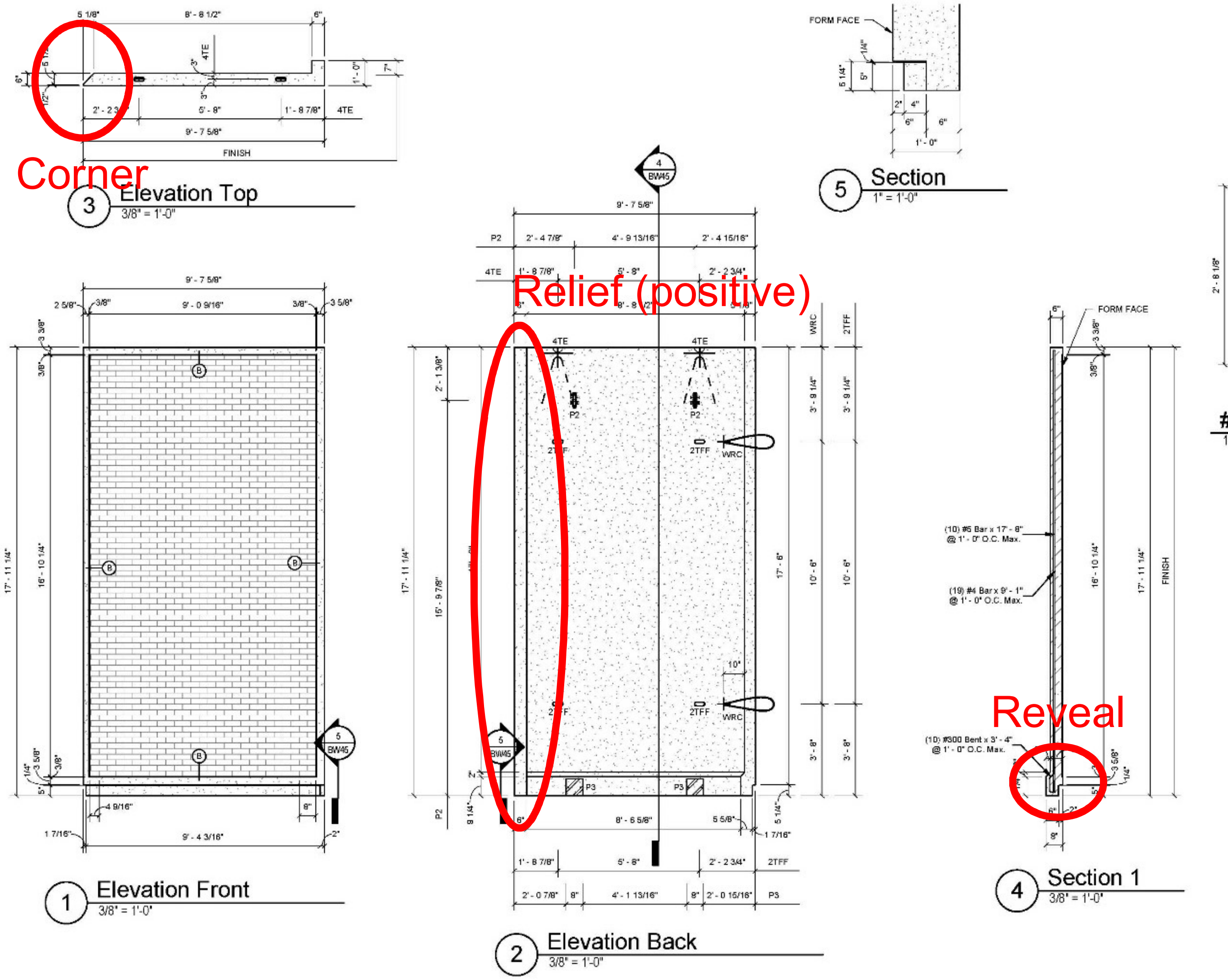


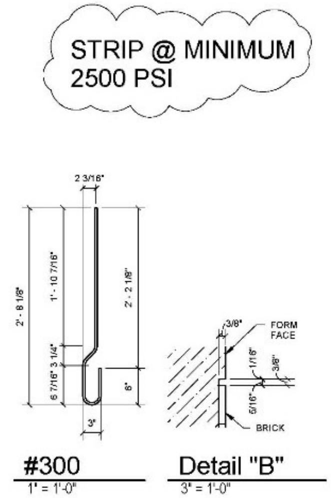


| Part List | | |
|---|---|---|
| Type | Description | Count |
| 2TFF | Burke 2-Ton Flat Anchor w/ (4)-#4x18" Lg. | 4 |
| 4TE | 4-Ton Erection Anchor w/ Shear & Ten. Bar | 2 |
| P2 | PSA 6035 Adjustable Insert | 2 |
| P3 | PL 3/8"x8"x0'-8" w/ (4)-1/2" Dia. x4" HS | 2 |
| WRC | 3/8" Dia. Wire Rope Cable | 2 |

| Rebar List | | |
|---|---|---|
| Type | Bar Length | Quantity |
| #4 Bar | 9' - 1" | 19 |
| #5 Bar | 17' - 8" | 10 |
| #300 Bent | 3' - 4" | 10 |
| #400 Bent | 2' - 7" | 19 |

| Material Takeoff | |
|---|---|
| Volume | Panel Weight |
| 89.68 CF | 13,344 |

| | | |
|---|---|---|
| 1 | 7/29/15 | ADD SECTION 5 |

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SHANDS MED. CENTER EXPANSION

SHOP TICKET

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| Project number | 3714 |
| Released date | 7/27/15 |
| Drawn by | SBF |
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# BW45 R1

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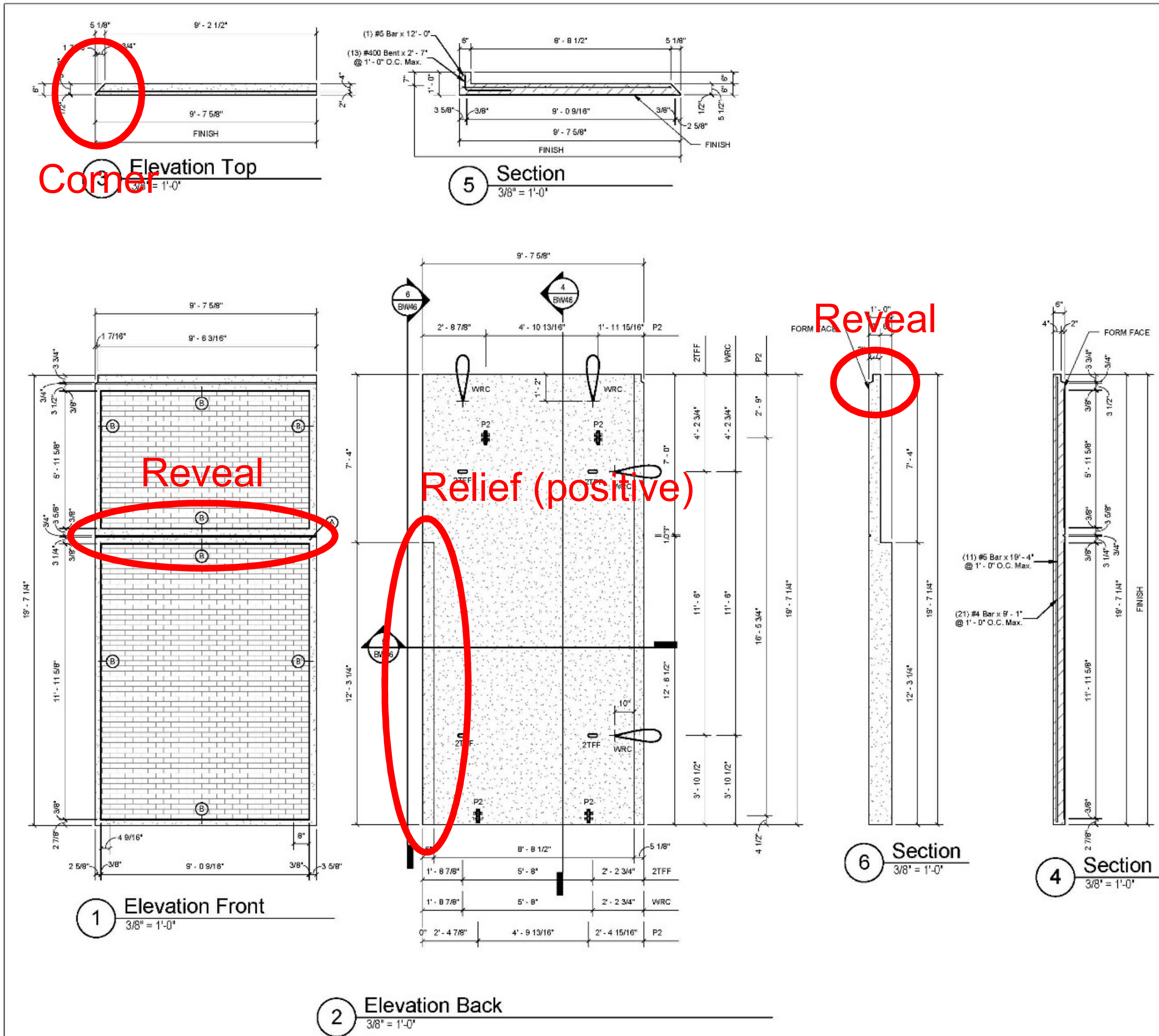


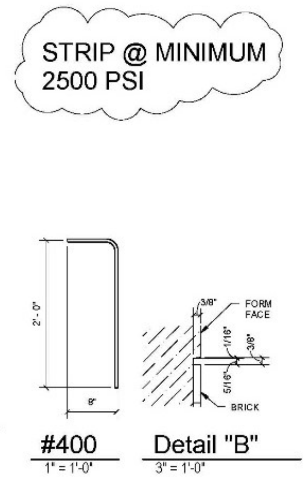


| Part List | | |
|---|---|---|
| Type | Description | Count |
| 2TFF | Burke 2-Ton Flat Anchor w/ (4)-#4x18" Lg. | 4 |
| P2 | PSA 6035 Adjustable Insert | 4 |
| WRC | 3/8" Dia. Wire Rope Cable | 4 |

| Rebar List | | |
|---|---|---|
| Type | Bar Length | Quantity |
| #4 Bar | 9' - 1" | 21 |
| #5 Bar | 12' - 0" | 1 |
| #5 Bar | 19' - 4" | 11 |
| #400 Bent | 2' - 7" | 13 |

| Material Takeoff | |
|---|---|
| Volume | Panel Weight |
| 94.98 CF | 14,118 |

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SHOP TICKET

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| Project number | 3714 |
| Released date | 7/20/15 |
| Drawn by | SBF |
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BW46

| | |
|---|---|
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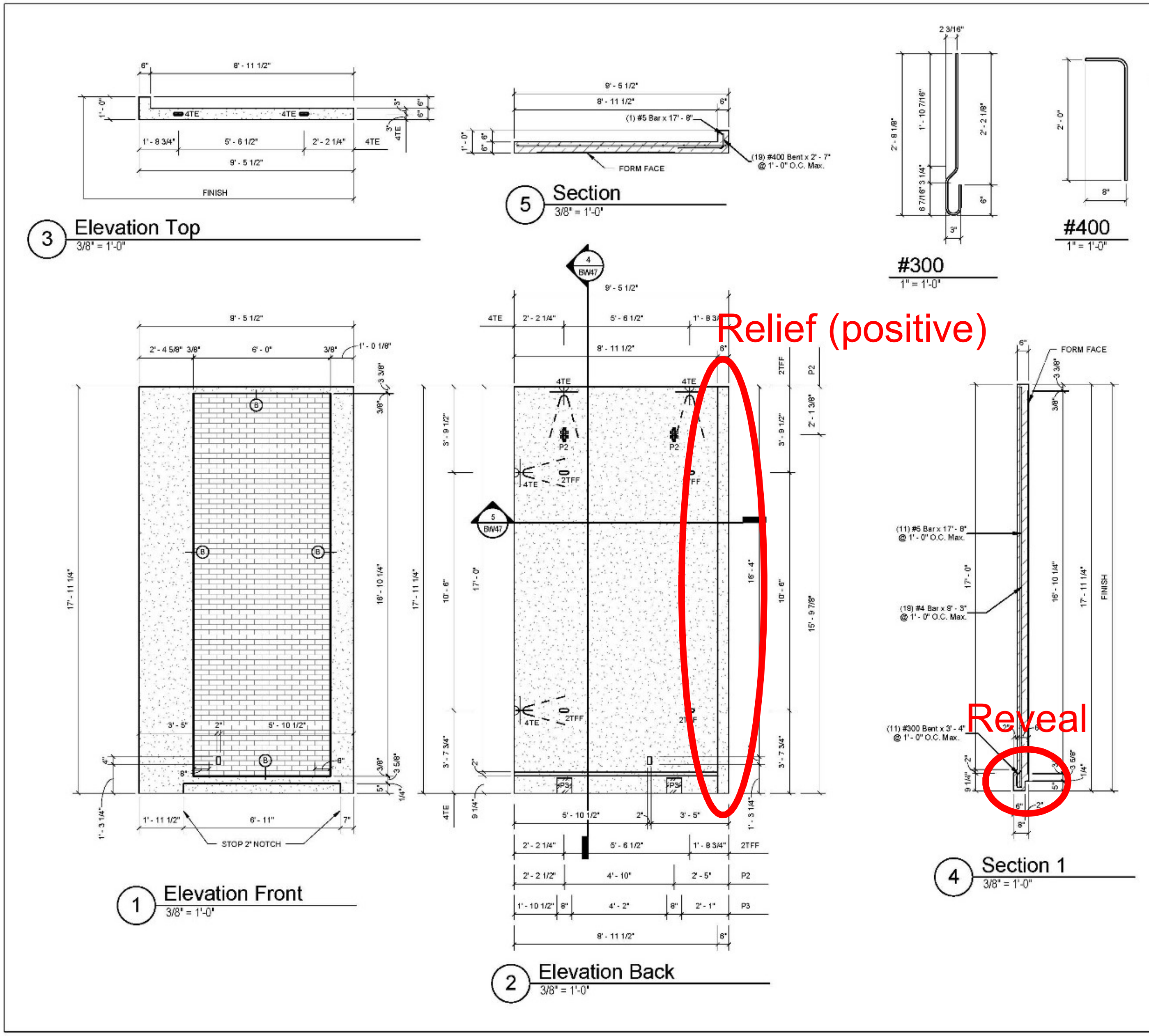


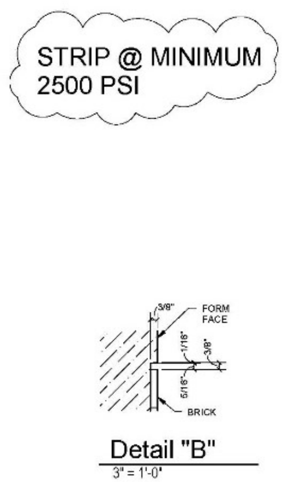


**Part List**

| Type | Description | Count |
|---|---|---|
| 2TFF | Burke 2-Ton Flat Anchor w/ (4)-#4x18" Lg. | 4 |
| 4TE | 4-Ton Erection Anchor w/ Shear & Ten. Bar | 4 |
| P2 | PSA 6035 Adjustable Insert | 2 |
| P3 | PL 3/8"x8"x0'-8" w/ (4)-1/2" Dia. x4" HS | 2 |

**Rebar List**

| Type | Bar Length | Quantity |
|---|---|---|
| #4 Bar | 9' - 3" | 19 |
| #5 Bar | 17' - 8" | 12 |
| #300 Bent | 3' - 4" | 11 |
| #400 Bent | 2' - 7" | 19 |

**Material Takeoff**

| Volume | Panel Weight |
|---|---|
| 90.12 CF | 13,458 |

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| Released date | 7/29/15 |
| Drawn by | SBF |
| Checked by | - |

# BW47

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|---|---|
| Number required | 1 |

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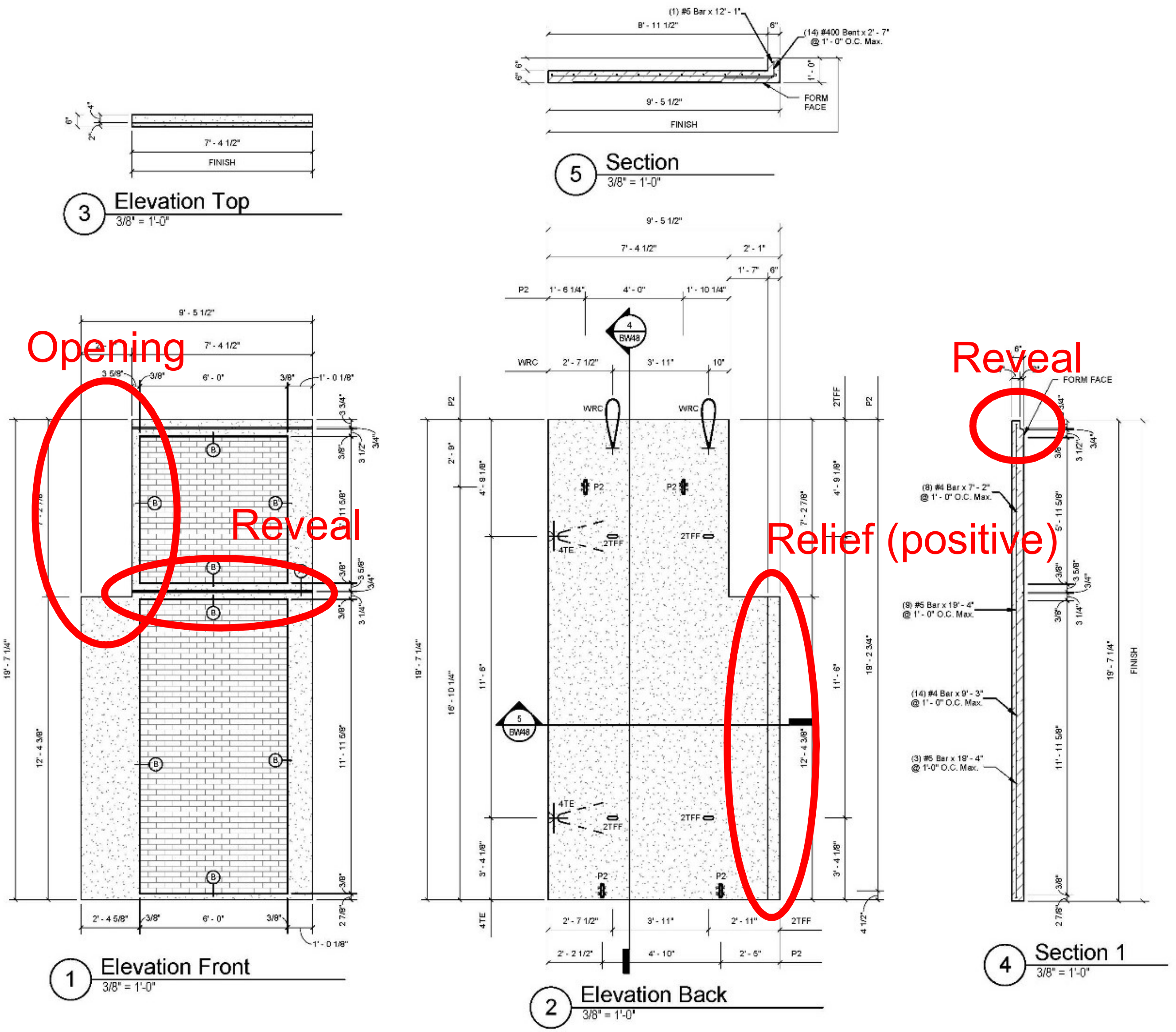
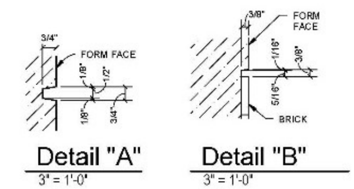



STRIP @ MINIMUM
2500 PSI




**Part List**

| Type | Description | Count |
|---|---|---|
| 2TFF | Burke 2-Ton Flat Anchor w/ (4)-#4x18" Lg. | 4 |
| 4TE | 4-Ton Erection Anchor w/ Shear & Ten. Bar | 2 |
| P2 | PSA 6035 Adjustable Insert | 4 |
| WRC | 3/8" Dia. Wire Rope Cable | 2 |

**Rebar List**

| Type | Bar Length | Quantity |
|---|---|---|
| #4 Bar | 7' - 2" | 8 |
| #4 Bar | 9' - 3" | 14 |
| #5 Bar | 12' - 1" | 4 |
| #5 Bar | 19' - 4" | 9 |
| #400 Bent | 2' - 7" | 14 |

**Material Takeoff**

| Volume | Panel Weight |
|---|---|
| 87.82 CF | 13,096 |

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SHOP TICKET

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|---|---|
| Project number | 3714 |
| Released date | 7/22/15 |
| Drawn by | SBF |
| Checked by | - |

# BW48

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|---|---|
| Number required | 1 |

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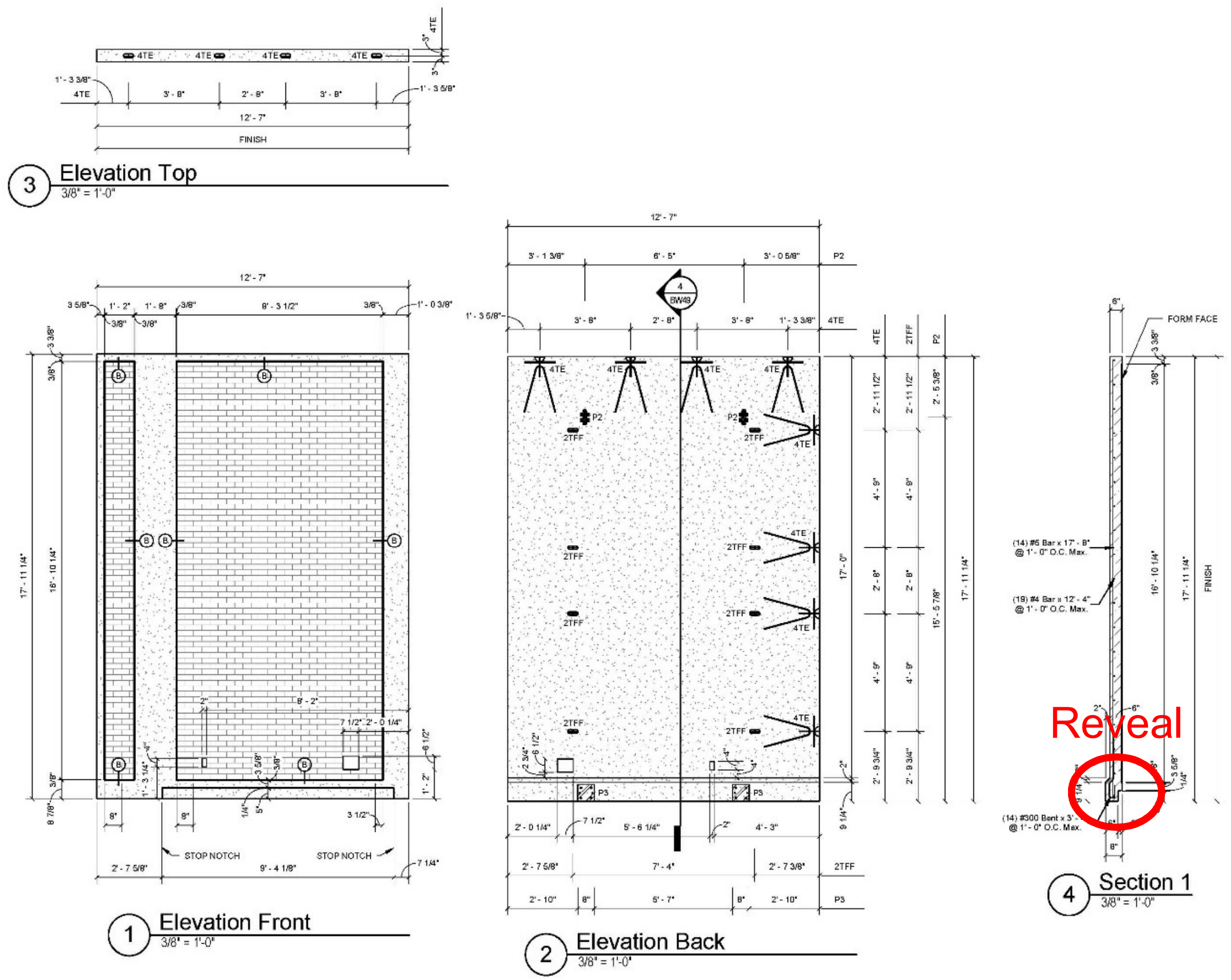
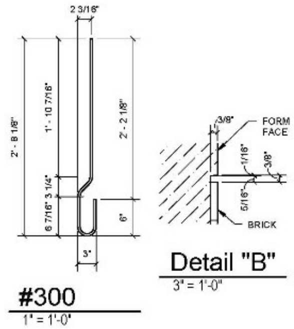
STRIP @ MINIMUM
2500 PSI




| Part List | | |
|---|---|---|
| Type | Description | Count |
| 2TFF | Burke 2-Ton Flat Anchor w/ (4)-#4x18" Lg. | 8 |
| 4TE | 4-Ton Erection Anchor w/ Shear & Ten. Bar | 8 |
| P2 | PSA 6035 Adjustable Insert | 2 |
| P3 | PL 3/8"x8"x0'-8" w/ (4)-1/2" Dia. x4" HS | 2 |

| Rebar List | | |
|---|---|---|
| Type | Bar Length | Quantity |
| #4 Bar | 12' - 4" | 19 |
| #5 Bar | 17' - 8" | 14 |
| #300 Bent | 3' - 4" | 14 |

| Material Takeoff | |
|---|---|
| Volume | Panel Weight |
| 113.85 CF | 16,982 |

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SHOP TICKET

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|---|---|
| Project number | 3714 |
| Released date | 7/21/15 |
| Drawn by | SBF |
| Checked by | - |

BW49

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|---|---|
| Number required | 1 |

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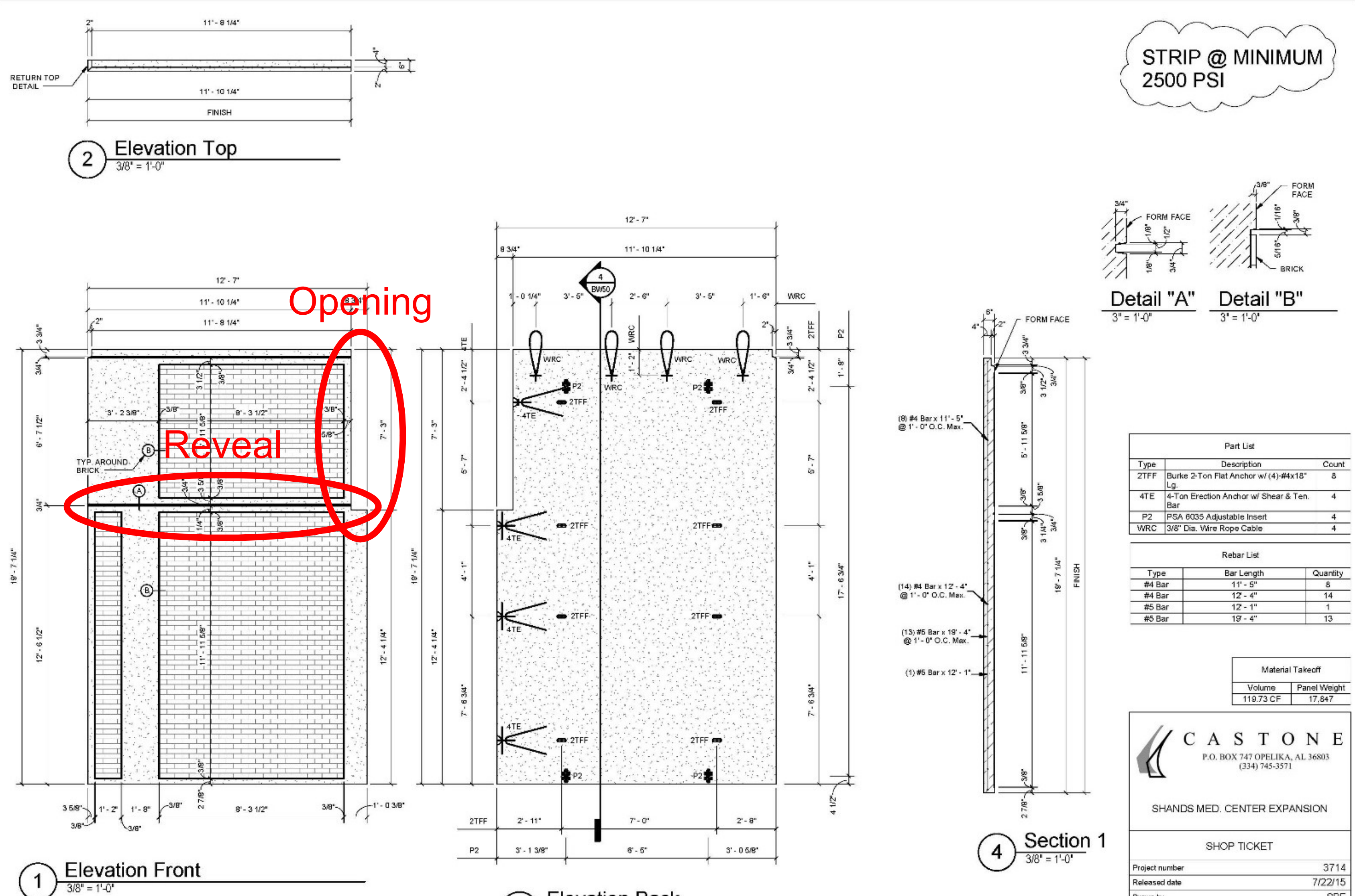


| Part List | | |
|---|---|---|
| Type | Description | Count |
| 2TFF | Burke 2-Ton Flat Anchor w/ (4)-#4x18" Lg. | 8 |
| 4TE | 4-Ton Erection Anchor w/ Shear & Ten. Bar | 4 |
| P2 | PSA 6035 Adjustable Insert | 4 |
| WRC | 3/8" Dia. Wire Rope Cable | 4 |

| Rebar List | | |
|---|---|---|
| Type | Bar Length | Quantity |
| #4 Bar | 11' - 5" | 8 |
| #4 Bar | 12' - 4" | 14 |
| #5 Bar | 12' - 1" | 1 |
| #5 Bar | 19' - 4" | 13 |

| Material Takeoff | |
|---|---|
| Volume | Panel Weight |
| 119.73 CF | 17,847 |

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| Project number | 3714 |
| Released date | 7/22/15 |
| Drawn by | SBF |
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# BW50

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|---|---|
| Number required | 1 |

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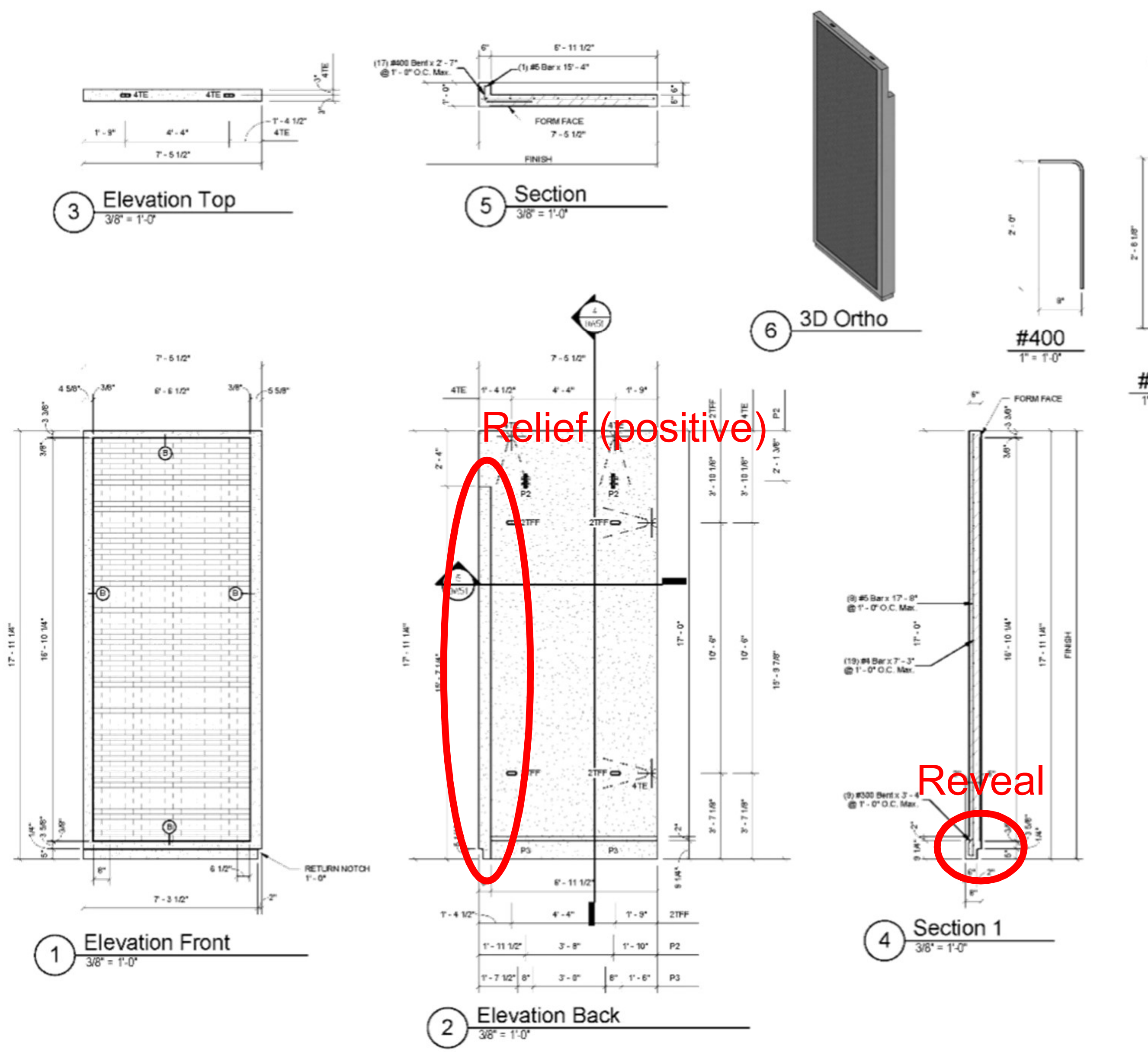
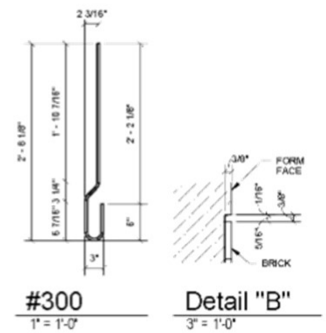



STRIP @ MINIMUM
2500 PSI




| Part List | | |
|---|---|---|
| Type | Description | Count |
| 2TFF | Burke 2-Ton Flat Anchor w/ (4)-#4x18" Lg. | 4 |
| 4TE | 4-Ton Erection Anchor w/ Shear & Ten. Bar | 4 |
| P2 | PSA 6035 Adjustable Insert | 2 |
| P3 | PL 3/8"x8"x0'-8" w/ (4)-1/2" Dia. x4" HS | 2 |

| Rebar List | | |
|---|---|---|
| Type | Bar Length | Quantity |
| #4 Bar | 7' - 3" | 19 |
| #5 Bar | 15' - 4" | 1 |
| #5 Bar | 17' - 8" | 8 |
| #300 Bent | 3' - 4" | 9 |
| #400 Bent | 2' - 7" | 17 |

| Material Takeoff | |
|---|---|
| Volume | Panel Weight |
| 71.24 CF | 10,619 |

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SHOP TICKET

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|---|---|
| Project number | 3714 |
| Released date | 7/30/15 |
| Drawn by | SBF |
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**BW51**

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|---|---|
| Number required | 1 |

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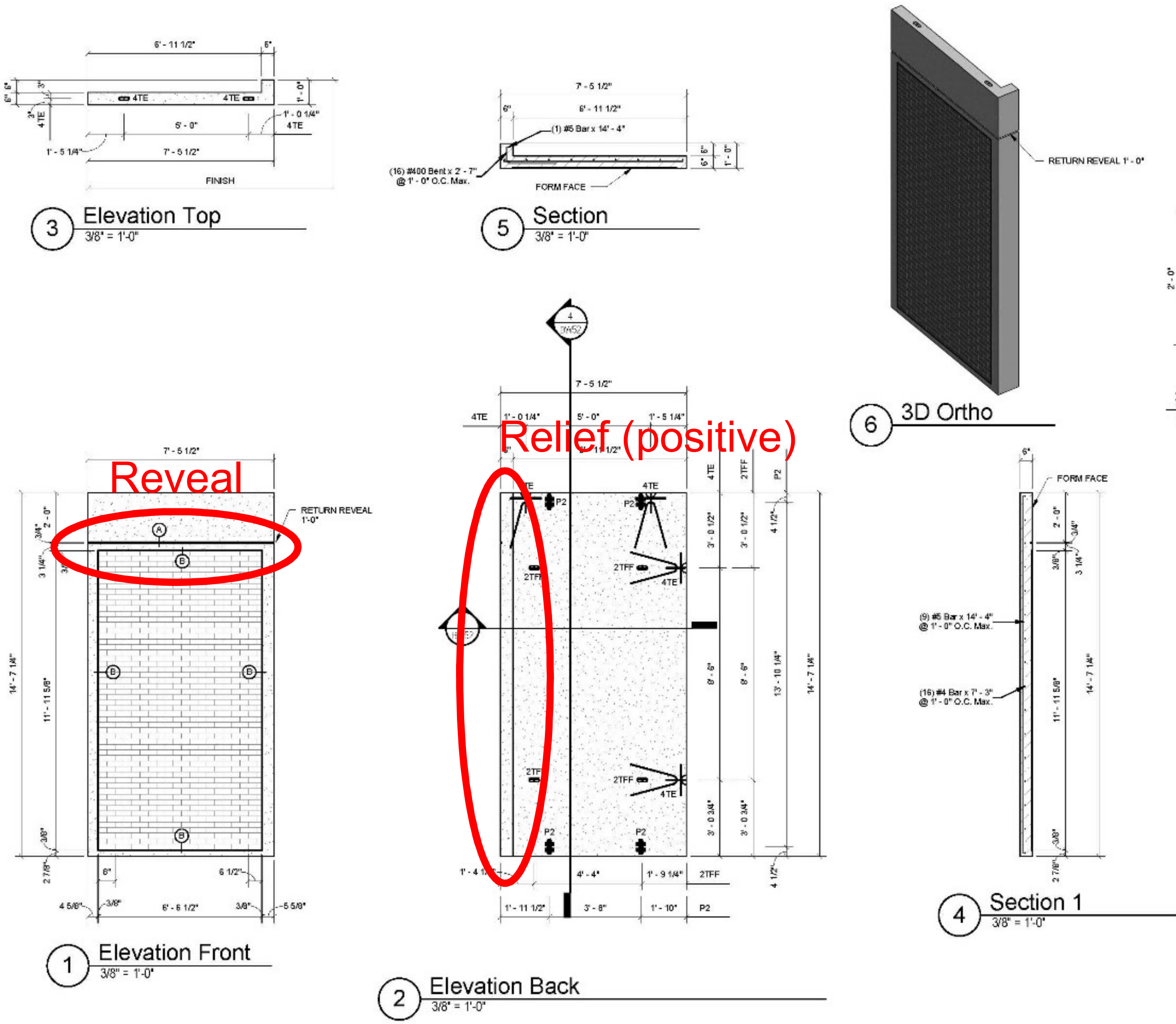
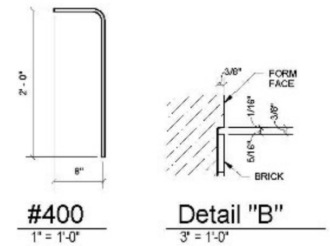
STRIP @ MINIMUM
2500 PSI




| Part List | | |
|---|---|---|
| Type | Description | Count |
| 2TFF | Burke 2-Ton Flat Anchor w/ (4)-#4x18" Lg. | 4 |
| 4TE | 4-Ton Erection Anchor w/ Shear & Ten. Bar | 4 |
| P2 | PSA 6035 Adjustable Insert | 4 |

| Rebar List | | |
|---|---|---|
| Type | Bar Length | Quantity |
| #4 Bar | 7' - 3" | 16 |
| #5 Bar | 14' - 4" | 10 |
| #400 Bent | 2' - 7" | 16 |

| Material Takeoff | |
|---|---|
| Volume | Panel Weight |
| 58.12 CF | 8,671 |

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SHOP TICKET

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|---|---|
| Project number | 3714 |
| Released date | 7/30/15 |
| Drawn by | SBF |
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**BW52**

| | |
|---|---|
| Number required | 1 |

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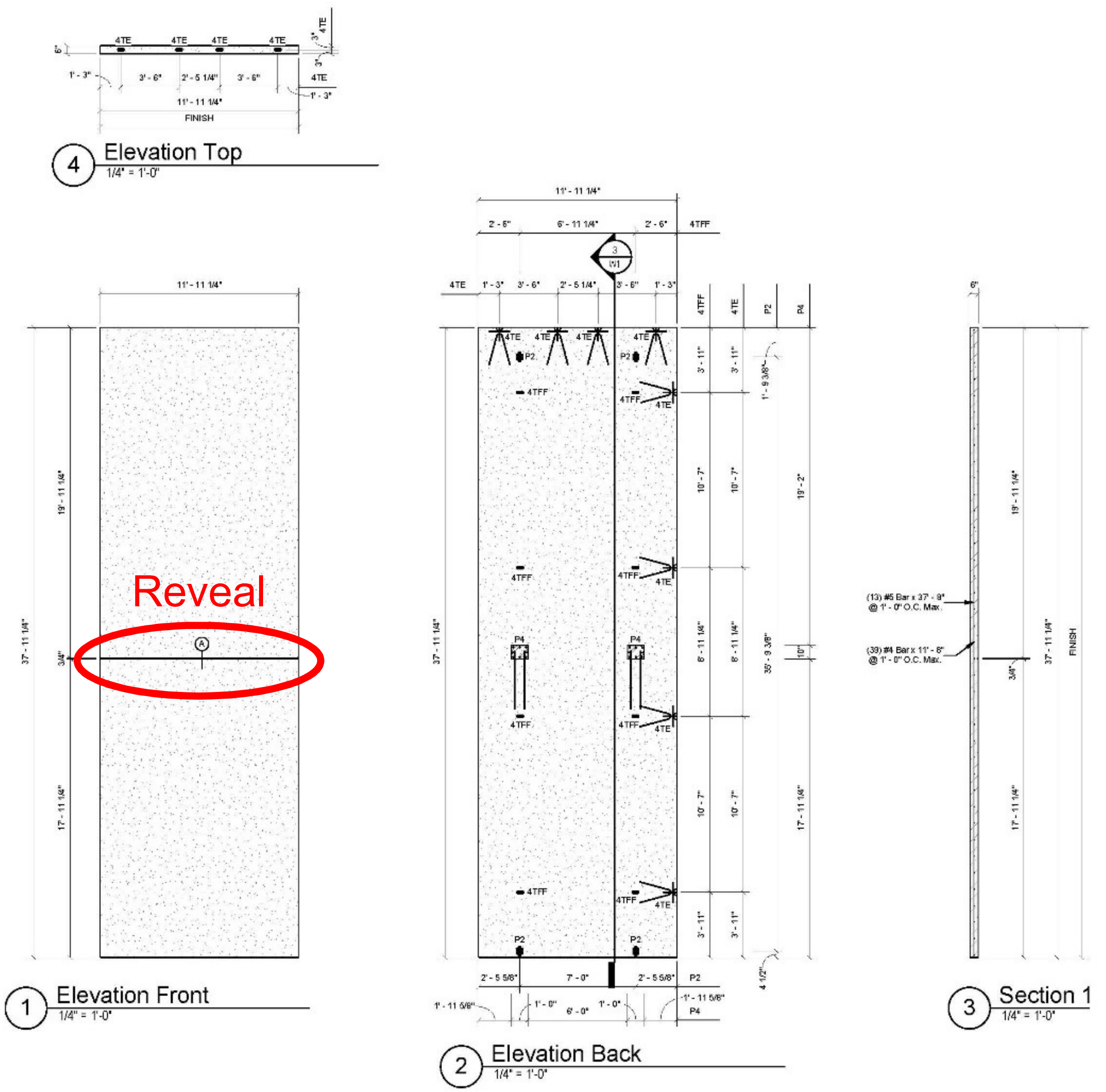
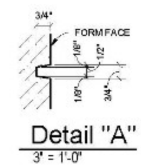
STRIP @ MINIMUM 2500 PSI




| Part List | | |
|---|---|---|
| Type | Description | Count |
| 4TE | 4-Ton Erection Anchor w/ Shear & Ten. Bar | 8 |
| 4TFF | Burke 4-Ton Flat Anchor w/ (4)-#4x18" Lg. | 8 |
| P2 | PSA 6035 Adjustable Insert | 4 |
| P4 | PL 1/2"x10"x1'-0" w/ (6)-1/2" Dia. x4" HS & (2)-#5x3'-6" | 2 |

| Rebar List | | |
|---|---|---|
| Type | Bar Length | Quantity |
| #4 Bar | 11' - 8" | 39 |
| #5 Bar | 37' - 8" | 13 |

| Material Takeoff | |
|---|---|
| Volume | Panel Weight |
| 226.61 CF | 34,083 |

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| Released date | 7/9/15 |
| Drawn by | SBF |
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W1

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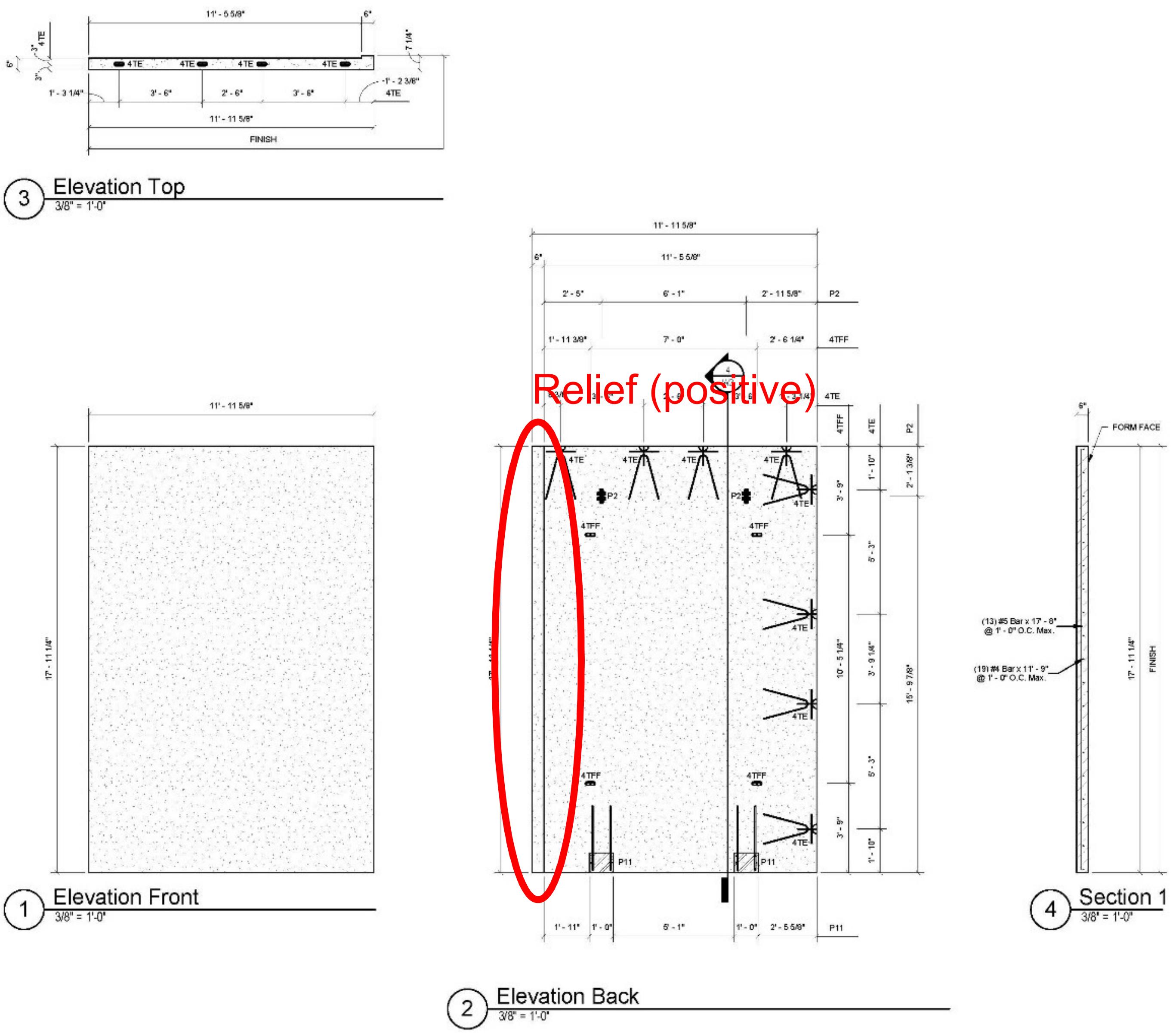
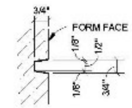
STRIP @ MINIMUM 2500 PSI




Detail "A"
3" = 1'-0"

| Part List | | |
|---|---|---|
| Type | Description | Count |
| 4TE | 4-Ton Erection Anchor w/ Shear & Ten. Bar | 8 |
| 4TFF | Burke 4-Ton Flat Anchor w/ (4)-#4x18" Lg. | 4 |
| P2 | PSA 6035 Adjustable Insert | 2 |
| P11 | PL 1/2"x10"x1'-0" w/ (2)-1/2" Dia. x3" HS & (2)-#5x3'-0" Bent | 2 |

| Rebar List | | |
|---|---|---|
| Type | Bar Length | Quantity |
| #4 Bar | 11' - 9" | 19 |
| #5 Bar | 17' - 8" | 13 |

| Material Takeoff | |
|---|---|
| Volume | Panel Weight |
| 108.47 CF | 16,337 |

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| Project number | 3714 |
| Released date | 7/10/15 |
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W2

Number required 1

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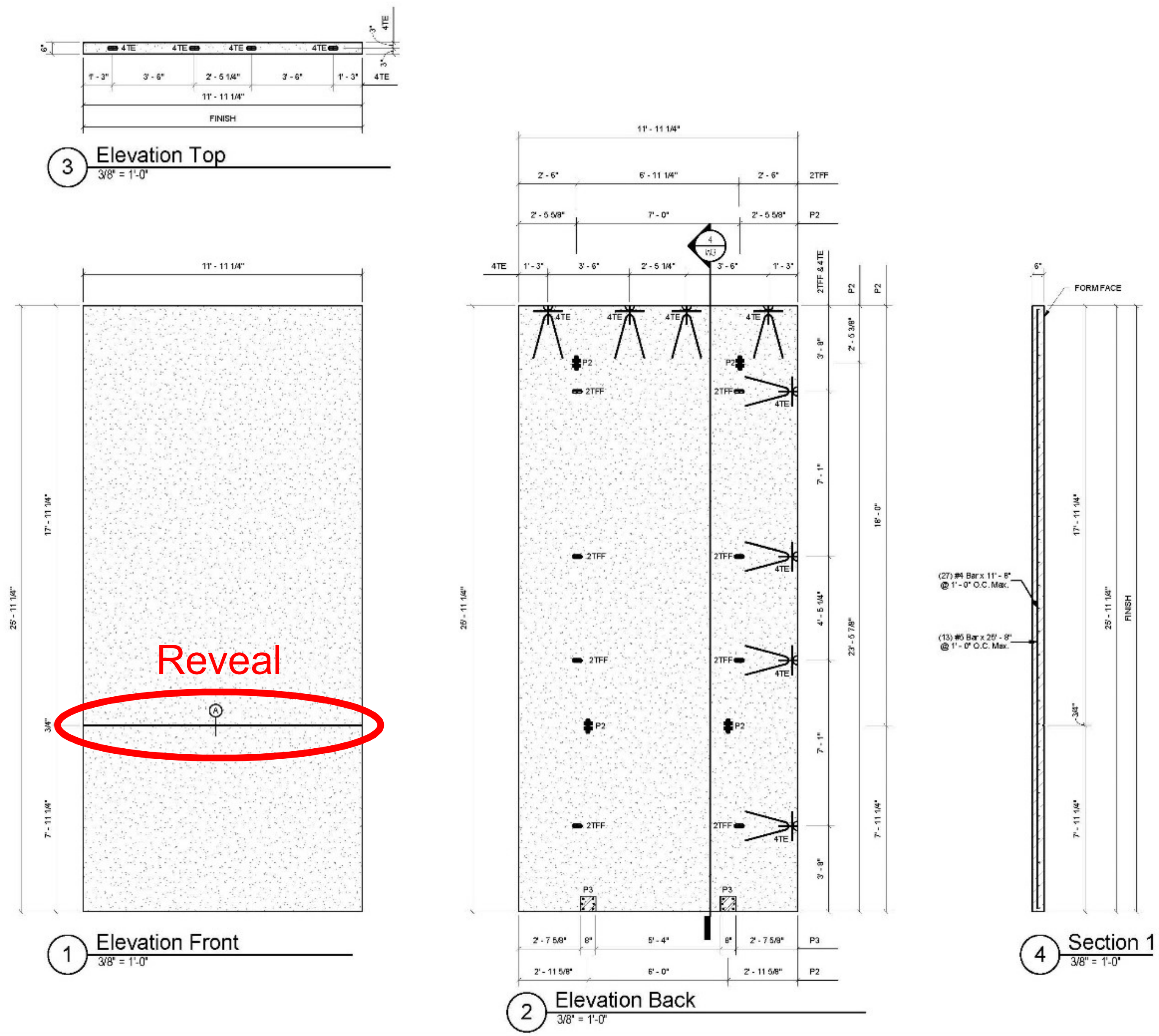
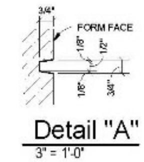
STRIP @ MINIMUM 2500 PSI




| Part List | | |
|---|---|---|
| Type | Description | Count |
| 2TFF | Burke 2-Ton Flat Anchor w/ (4)-#4x18" Lg. | 8 |
| 4TE | 4-Ton Erection Anchor w/ Shear & Ten. Bar | 8 |
| P2 | PSA 6035 Adjustable Insert | 4 |
| P3 | PL 3/8"x8"x0'-8" w/ (4)-1/2" Dia. x4" HS | 2 |

| Rebar List | | |
|---|---|---|
| Type | Bar Length | Quantity |
| #4 Bar | 11' - 8" | 27 |
| #5 Bar | 25' - 8" | 13 |

| Material Takeoff | |
|---|---|
| Volume | Panel Weight |
| 164.93 CF | 23,288 |

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| Project number | 3714 |
| Released date | 7/10/15 |
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W3

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| Number required | 1 |

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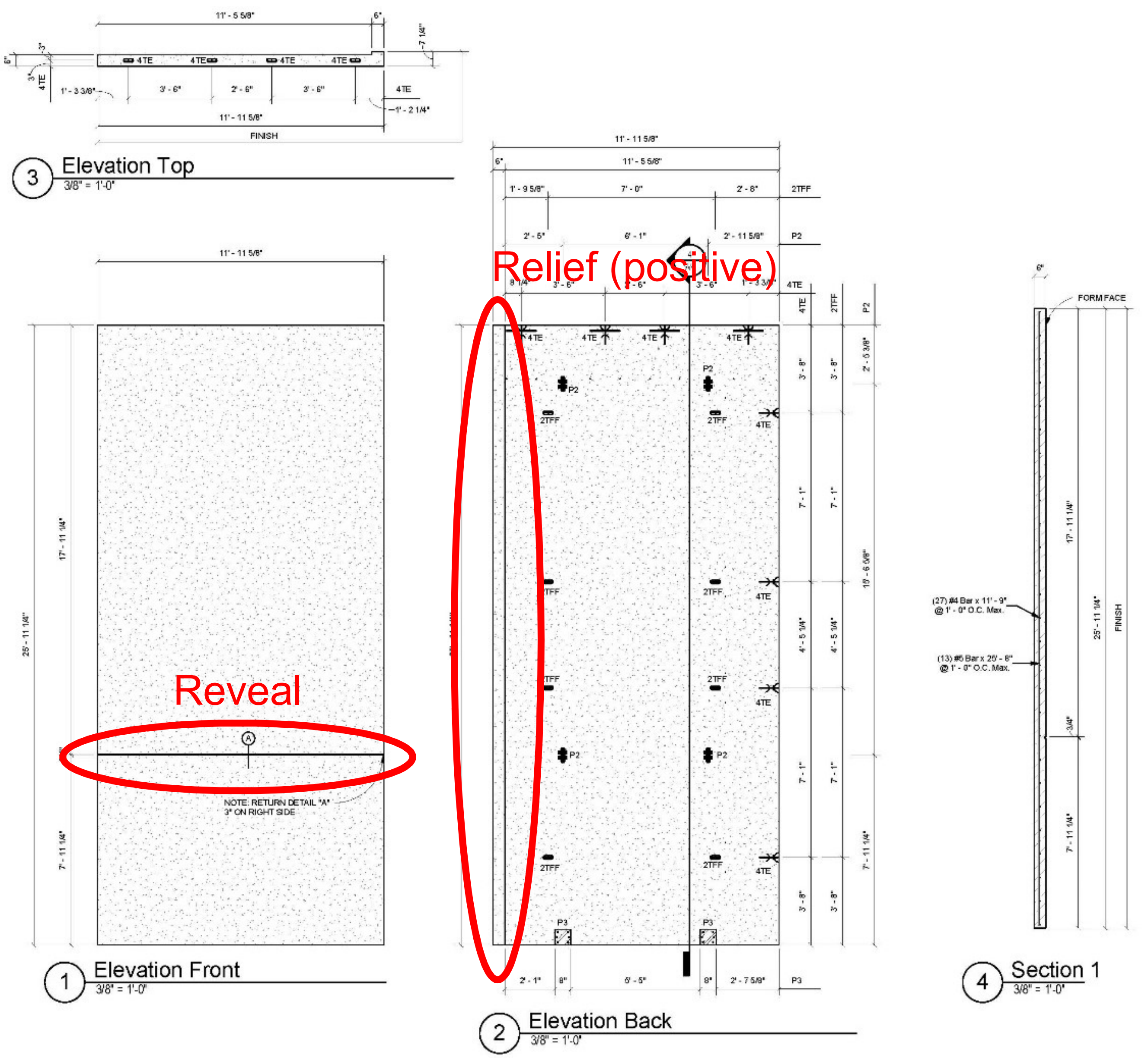
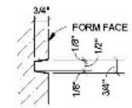



STRIP @ MINIMUM 2500 PSI




Detail "A"
3" = 1'-0"

| Part List | | |
|---|---|---|
| Type | Description | Count |
| 2TFF | Burke 2-Ton Flat Anchor w/ (4)-#4x18" Lg. | 8 |
| 4TE | 4-Ton Erection Anchor w/ Shear & Ten. Bar | 8 |
| P2 | PSA 6035 Adjustable Insert | 4 |
| P3 | PL 3/8"x8"x0'-8" w/ (4)-1/2" Dia. x4" HS | 2 |

| Rebar List | | |
|---|---|---|
| Type | Bar Length | Quantity |
| #4 Bar | 11' - 9" | 27 |
| #5 Bar | 25' - 8" | 13 |

| Material Takeoff | |
|---|---|
| Volume | Panel Weight |
| 156.68 CF | 23,551 |

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| Project number | 3714 |
| Released date | 7/10/15 |
| Drawn by | SBF |
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W4

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| Number required | 1 |

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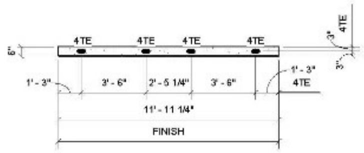
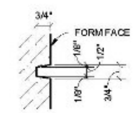
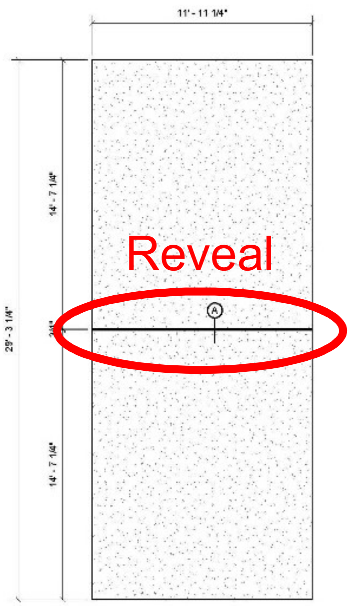
STRIP @ MINIMUM
2500 PSI



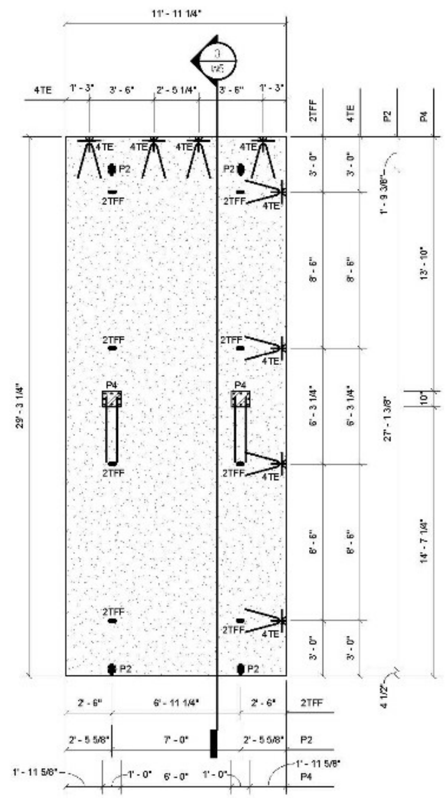

4 Elevation Top
1/4" = 1'-0"



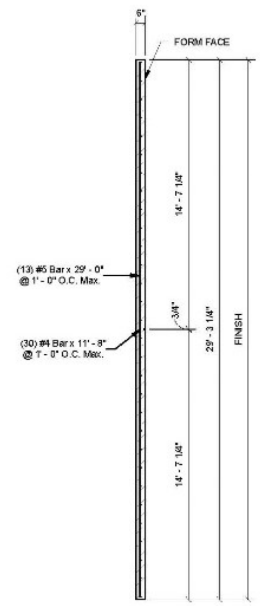

Detail "A"
3" = 1'-0"




1 Elevation Front
1/4" = 1'-0"




2 Elevation Back
1/4" = 1'-0"




3 Section 1
1/4" = 1'-0"

| Part List | | |
|---|---|---|
| Type | Description | Count |
| 2TFF | Burke 2-Ton Flat Anchor w/ (4)-#4x18" Lg. | 8 |
| 4TE | 4-Ton Erection Anchor w/ Shear & Ten. Bar | 8 |
| P2 | PSA 6035 Adjustable Insert | 4 |
| P4 | PL 1/2"x10"x1'-0" w/ (6)-1/2" Dia. x4" HS & (2)-#5x3'-6" | 2 |

| Rebar List | | |
|---|---|---|
| Type | Bar Length | Quantity |
| #4 Bar | 11' - 8" | 30 |
| #5 Bar | 29' - 0" | 13 |

| Material Takeoff | |
|---|---|
| Volume | Panel Weight |
| 174.88 CF | 26.303 |

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|---|---|
| Project number | 3714 |
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| Checked by | - |

W5

| | |
|---|---|
| Number required | 2 |

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# APPENDIX E. MODELLING PANEL FAMILIES

Example panel models are defined using the software *Revit*, a popular digital modelling software among architectural designers. *Revit* has also become a popular tool among contractors for project coordination. Steps for creating a digital models of panel models with various geometrical features are described in this appendix.

## E.1 Flat (panel)

Each panel type is developed as a *Revit Family.* This allows future customization of designated parameter values. The simplest example – Flat – is shown in Figure 149.

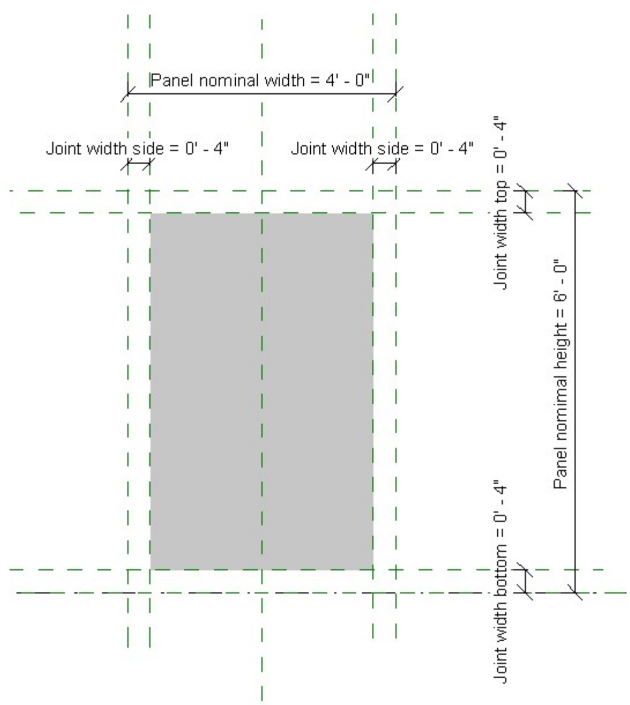



**Figure 149: Flat panel front view**

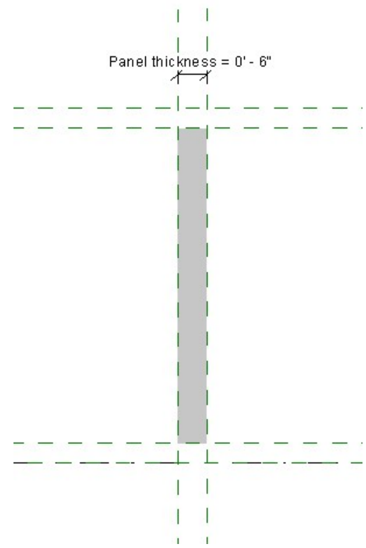
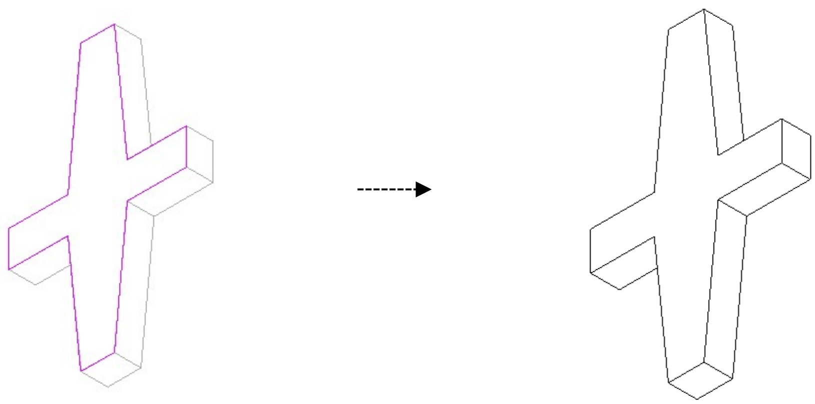



**Figure 150: Flat panel right side view**

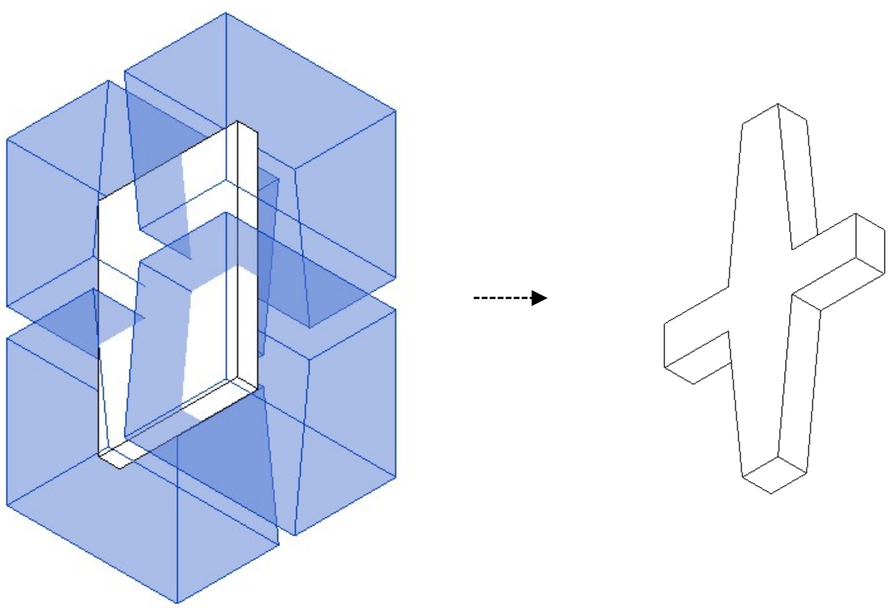
The flat panel is a simple extruded rectangle. The panel geometry is locked to a series of *Reference Planes. Instance Parameter* dimensions between these *Reference Planes* control the height, width, and thickness of the panel. Joint widths control the dimension between the panel boundary (defined on the building surface) and the edge of the panel geometry. Thus, the difference between nominal and actual dimensions. Similar modelling logic is used for other panel types which use the flat panel as a base condition.

## E.2 Non-rectangular

Instead of beginning with a rectangular profile, as in the flat panel, non-rectangular panels can begin with any profile shape. Many times, this profile will be determined by the panel boundaries from the scaffold model. However, the profile can also be defined through the panel model and then applied to a pattern across a building model surface. The profile can be defined in a number of ways, which has an effect on the functionality of the model. For example, the panel shown in Figure 151 can either be defined as a filled outline (a), or as a series of *Void Extrusions* removed from a flat panel (b).



a



b

**Figure 151: Defining profile for non-rectangular panel**

### E.3 Opening (window)

The addition of an opening to the panel creates a much more complex set of parameters. In addition, decisions have to be made about how the opening is defined. For the model shown in Figure 152, four parameters control the opening: window height, window width, window X location, and window Z location. The opening is created using a *Void Extrusion*, defining a size and insertion point for the opening. There are numerous other ways to define the opening. For example, the opening could be sized and located by providing a dimension from each of the edges of the panel. If the opening has always centered on the panel, just two dimensions would be required; a top and bottom dimension and a side dimension. The opening could also be located in relation to the center of the panel instead of from the sides.

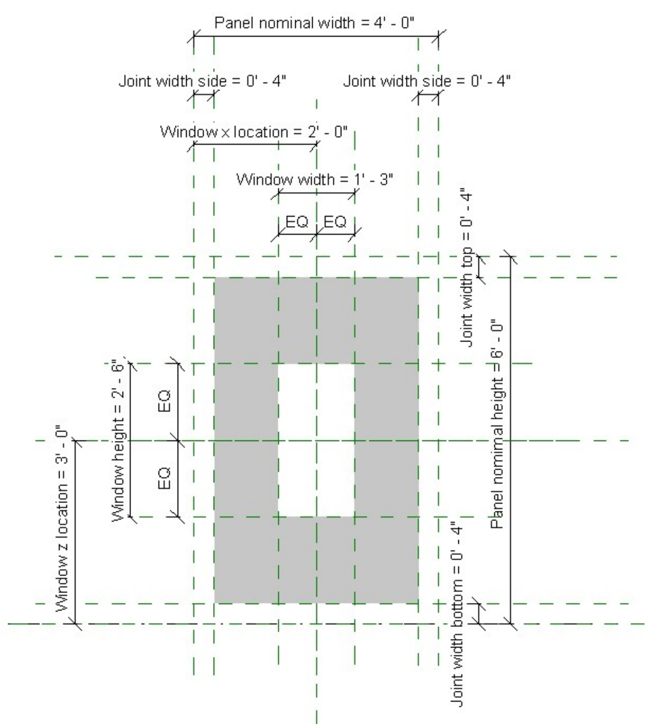



**Figure 152: Opening panel front view**

## E.4 Opening (non-rectangular)

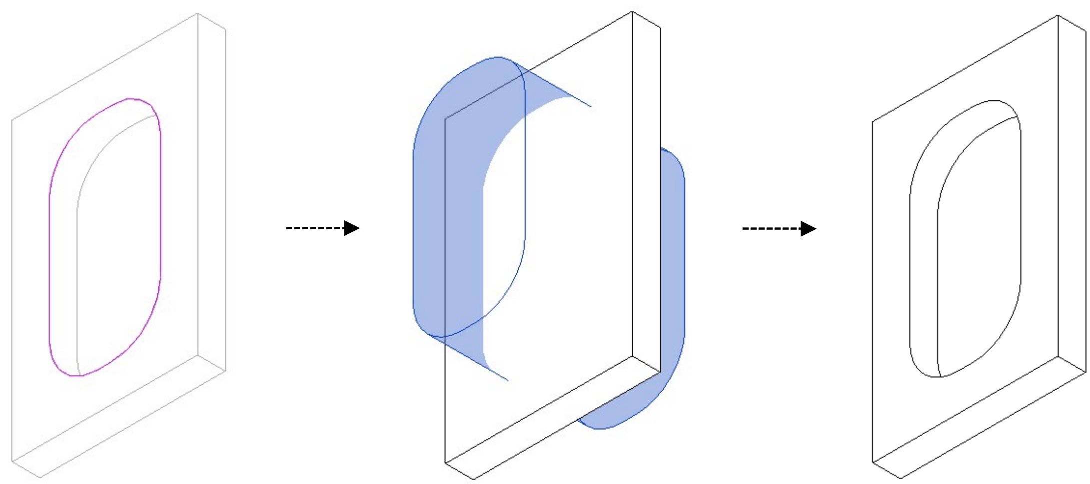


**Figure 153: Defining profile for non-rectangular opening**

A non-rectangular opening is defined by a customized *Void Extrusion* profile. The openings for the panel in Figure 153 are created made by varying the fillet radius of a rectangular *Void Extrusion.* Other buildings may have even more complex opening geometry, such as lofted parametric forms which would be an extension of this model definition; defining two or more profiles rather than a single extruded profile.

## E.5 Facet (negative and positive)

There are two types of facets; negative and positive. The negative facet carves away material from the flat panel and is created using a *Void Blend.* The positive facet adds material to the flat panel and is created using a *Blend. Blends* are similar to “lofted” geometry in other software; two profiles are defined and the *blend* tool creates surfaces to connect the profiles. In both the positive and negative cases, the profiles are rectangles.

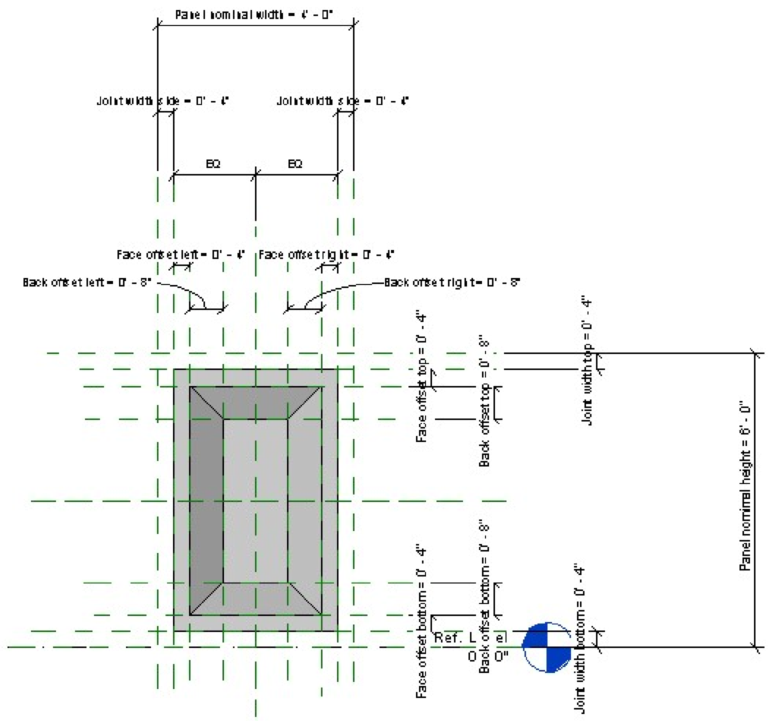



**Figure 154: Facet negative panel front view**

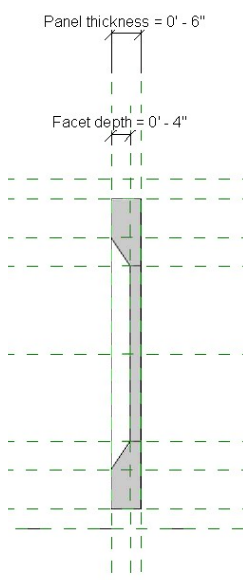



**Figure 155: Facet negative panel right side view**

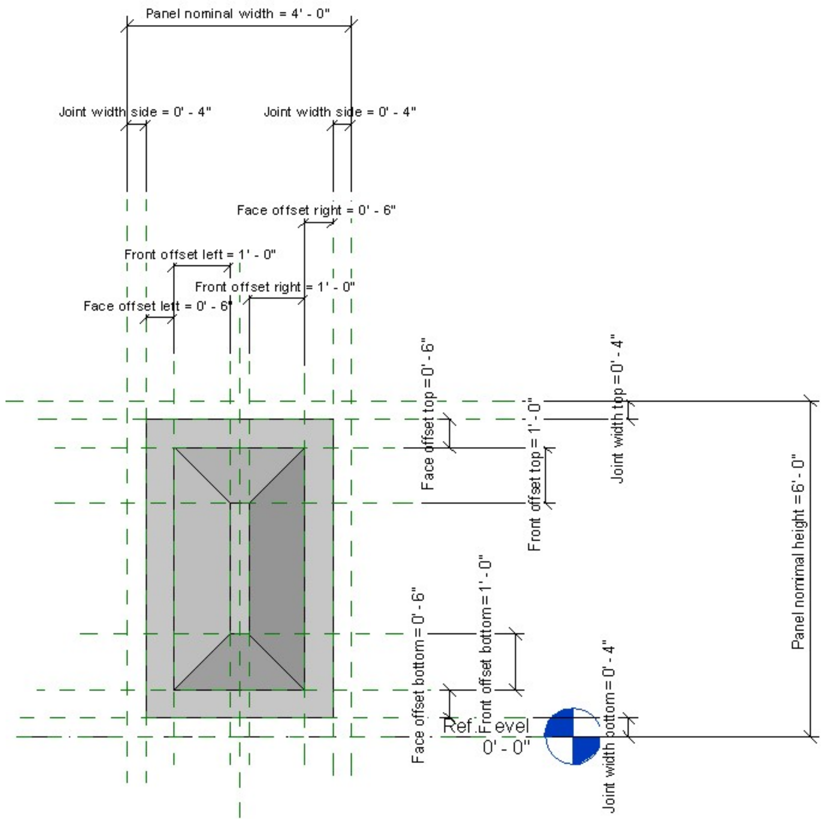



**Figure 156: Facet positive panel front view**

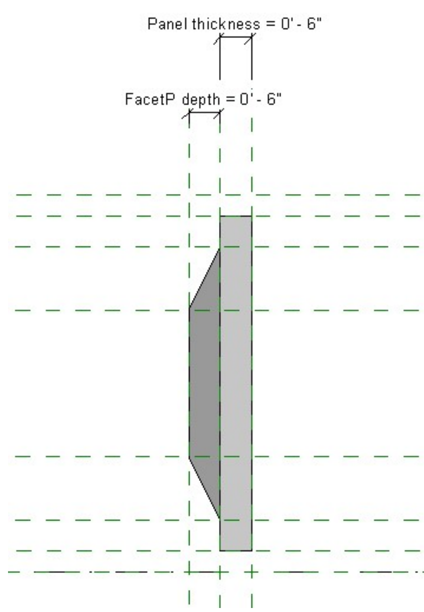



**Figure 157: Facet positive panel right side view**

The size and location of these rectangles is controlled by nine parameters: back (and front) offset bottom, back (and front) offset left, back (and front) offset right, back (and front) offset top, face offset bottom, face offset left, face offset right, face offset top and facet depth.

## E.6 Facet + opening

In addition to be ability of panels to contain multiple features, features can be referenced to one another. The facet + opening panel is one such example. Even though there is additional geometry to control, there are no additional features because the “back” of the facet *Void Blend* is connected to the same *Reference Planes* as the opening *Void Extrusion.* The result is that as the opening height, width, and location are adjusted the facet will also be modified, and vice versa.

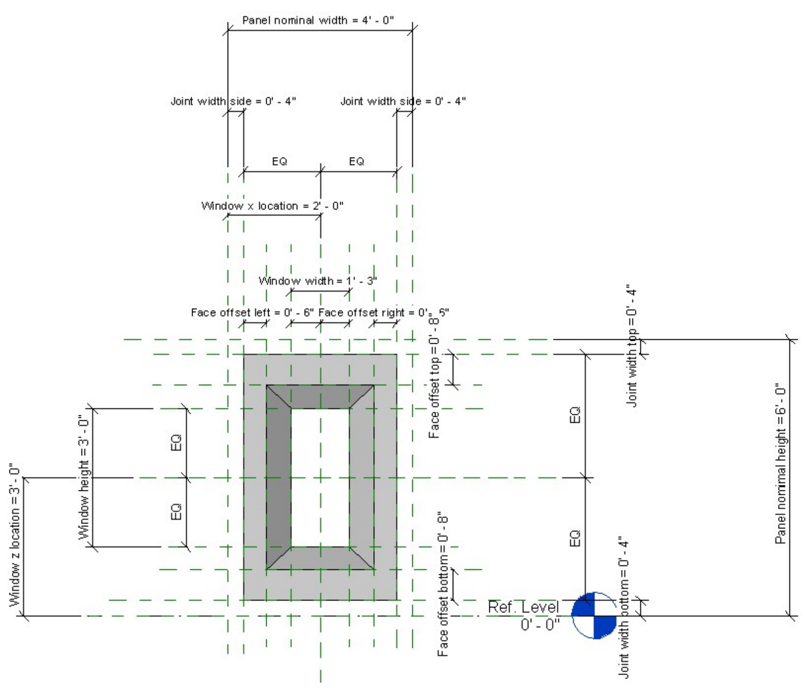



**Figure 158: Facet + opening panel front view**

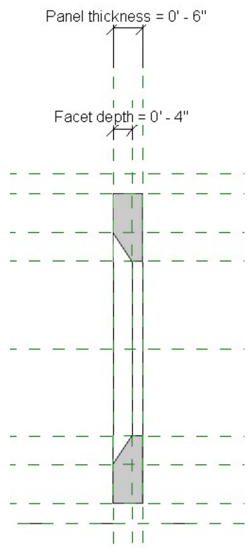



**Figure 159: Facet + opening panel right side view**

## E.7 Reveal

Current models include two types of reveals: horizontal and vertical. The three parameters that control the *Void Extrusion* creating the reveal geometry are depth, width, and location. Future work could allow non-orthogonal reveals. Or, non-orthogonal reveals could be implemented through the modelling techniques currently described for "relief patterns." It is also worth noting fabrication issues of such geometry (i.e. reveals will not be perfectly rectangular because of issues of construction and weather proofing.)

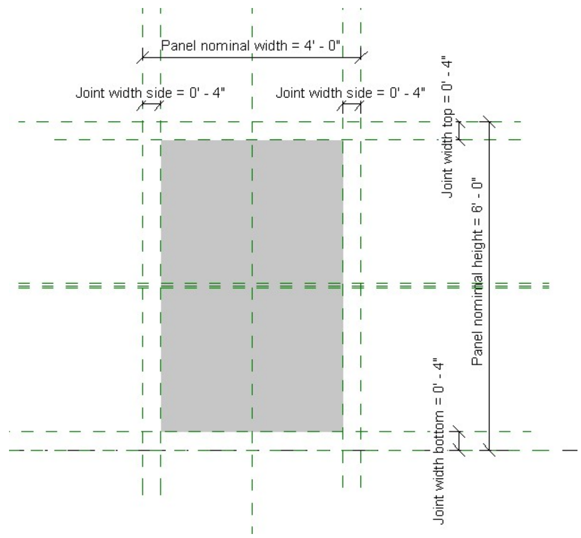



**Figure 160: Horizontal reveal panel front view**

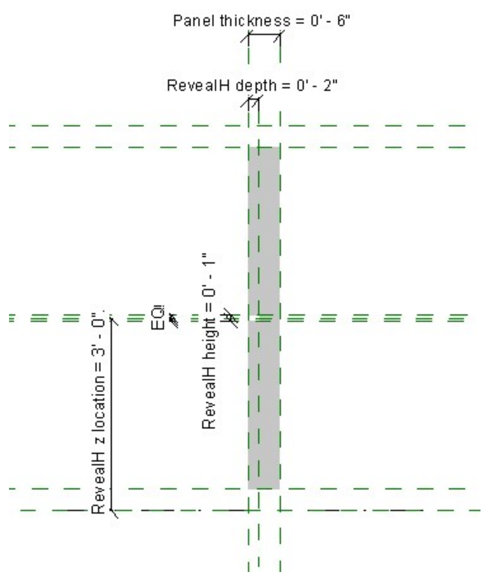



**Figure 161: Horizontal reveal panel right side view**

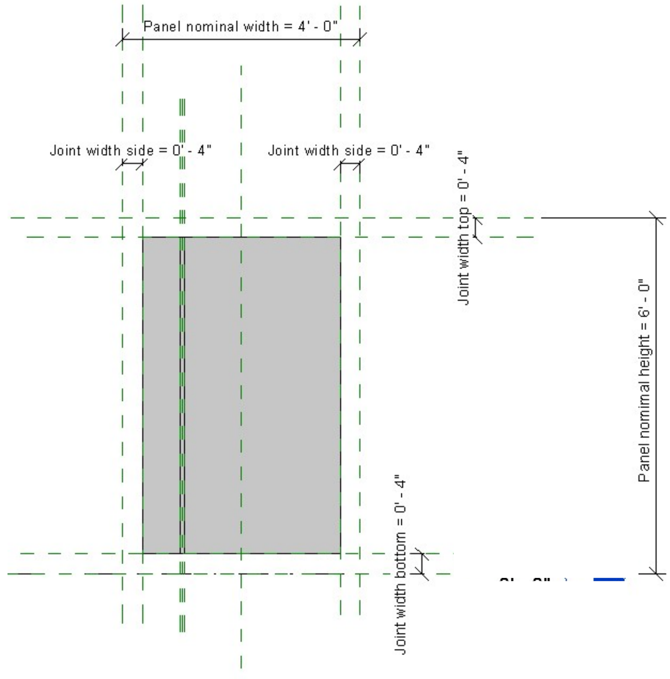



**Figure 162: Vertical reveal panel front view**

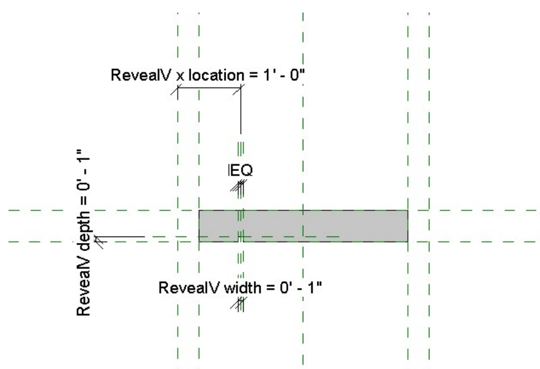



**Figure 163: Vertical reveal panel plan view**

## E.8 Notch

The notch feature is similar to both reveal and relief area (discussed below) in geometrical construction; a controlled *Void Extrusion* removes a portion of the panel. The three parameters that control the notch geometry are depth, width, and location.

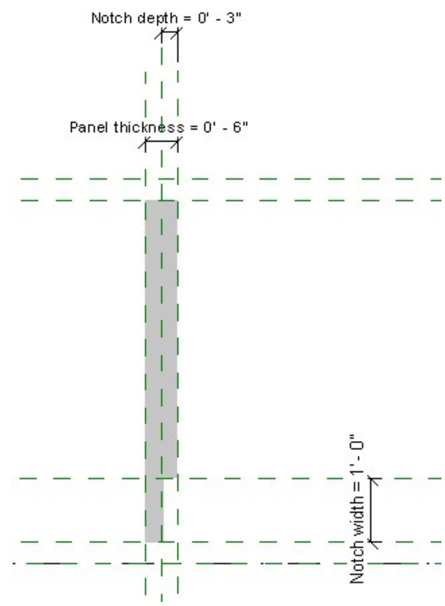



**Figure 164: Notch panel right side view**

## E.9 Taper

*Void Extrusion* is used to create taper panels by adjusting the top or bottom of the front face of the panel. This could be modified to adjust the right or left side, or the back face of the panel. In addition, panels may have even more complex opening geometry, such as lofted parametric forms which would be an extension of this model definition; creating two or more profiles to blend together rather than a single extruded profile.

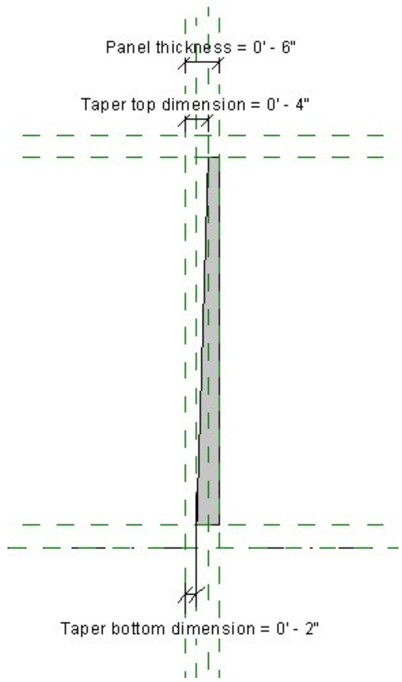



**Figure 165: Taper panel right side view**

## E.10 Rib

Ribs are defined by a custom profile drawn on the front face of a panel. This profile is then extruded. It could be that the shape is not extruded directly, but rather is lofted to another profile; an extension of this model definition. For the current model, in addition to the profile, there is a rib depth parameter.

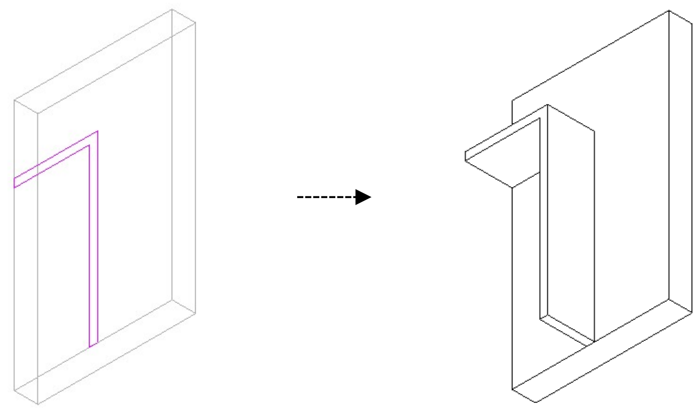


**Figure 166: Defining profile for rib panel**

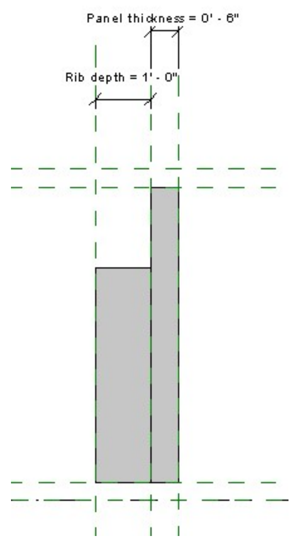



**Figure 167: Rib panel right side view**

## E.11 Hole (circular)

Holes are similar is geometrical construction and parametric control to openings, created by a *Void Extrusion.* Also similar to openings, there is the possibility of inserting other shapes besides a circle as the profile of the hole. Holes are defined by a profile and a location.

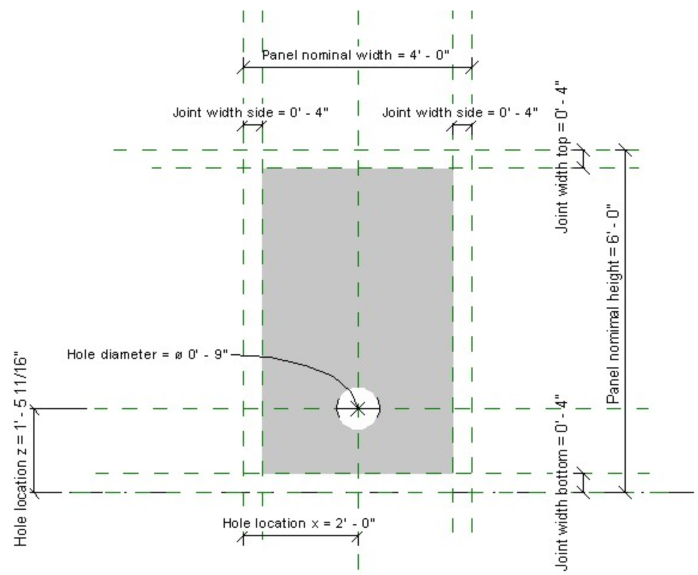



**Figure 168: Hole panel front view**

## E.12 Relief patterns and areas (negative and positive)

Relief areas are also similar to openings; however, an additional variable controls the depth as opposed to allowing the *Void Extrusion* to pass through the entire thickness of the panel. Relief areas also required a profile and a location. For relief patterns, an additional layer of pattern is applied across the panel face to which the relief is applied.

Possibilities for patterning are endless. Visual scripting using the software *Dynamo* defines the surface pattern.

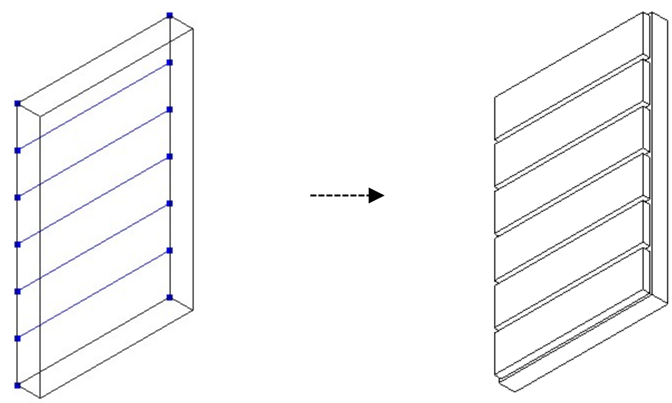


**Figure 169: Defining pattern for relief**

## E.13 Relief + opening

Similar to facet + opening, another oft-used combination of features is relief + opening. Relief and opening geometry can be related in any number of ways – one example in shown in Figures 170 and 171. When the *Void* Extrusion associated with the relief geometry is associated with the same *Reference Planes* as the *Void Extrusions* controlling the opening geometry, the result is that as the relief height, width, and location is adjusted the opening will also be modified, and vice versa. The relief portion maintains its depth variable. As with other features and combination of features, the method of organizing and constraining the model effects the possible panel variations.

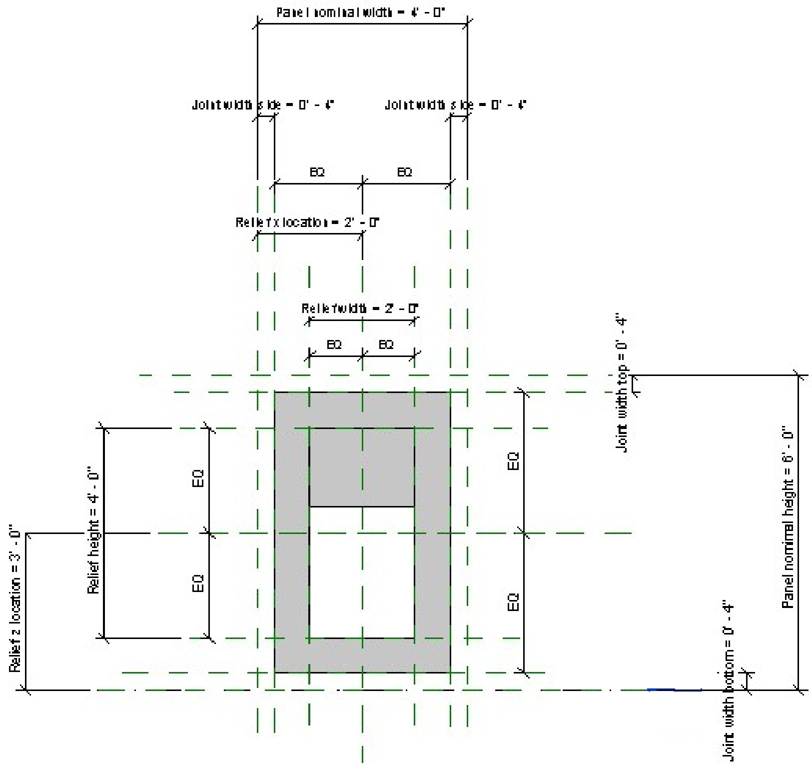



**Figure 170: Relief + opening panel front view**

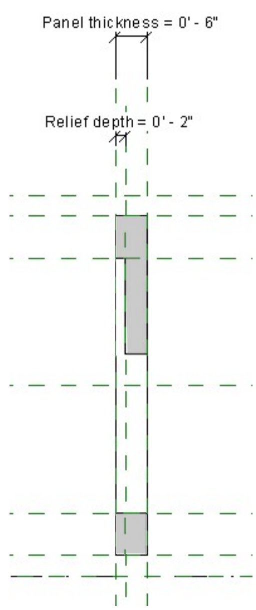



**Figure 171: Relief + opening panel right side view**

## E.14 Perforated pattern

Similar to relief patterns, the additional layer of pattern applied across the panel face can be used to create perforations. Again, the possibilities for patterning are endless. Variables include pattern and profile (the shape that is cut through the panel). Visual scripting using the software *Dynamo* defines the surface pattern.

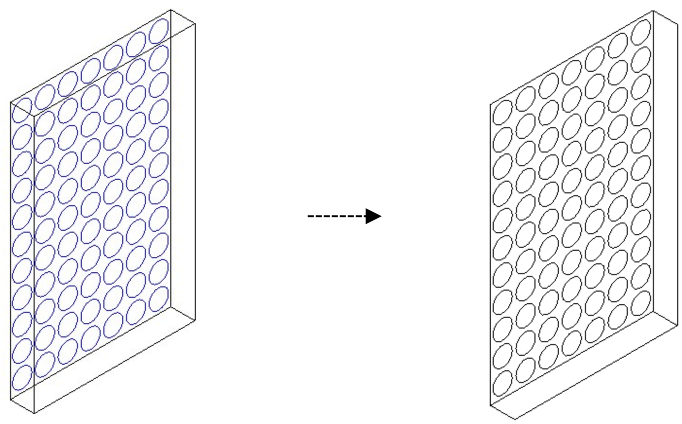


**Figure 172: Defining pattern for perforation**

## E.15 Corner

Creating a corner panel involves either joining two or more panels together or using a *Void Extrusion* to create mitred corner panel.

## E.16 Gesture

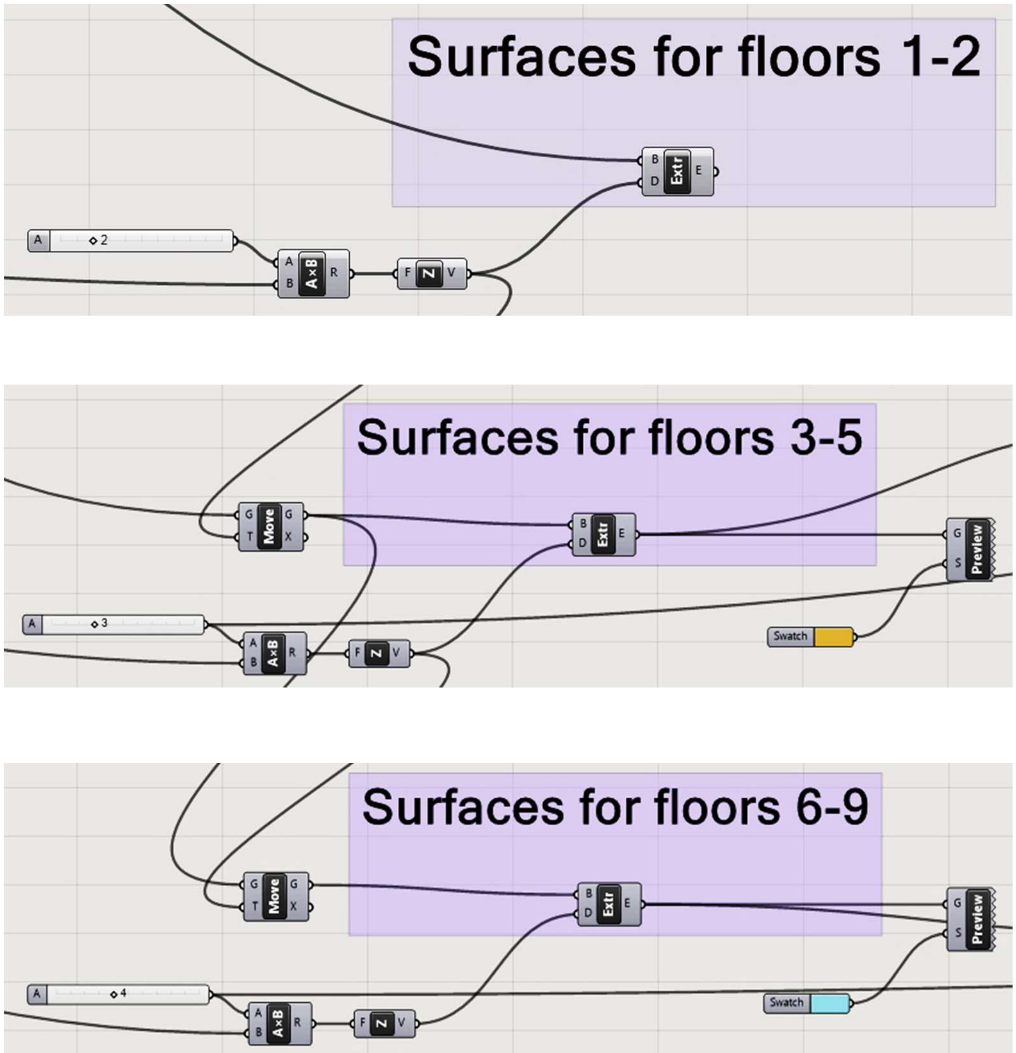
The gesture panel considers the notion that geometrical features sometimes span across two or more panels. This concept is discussed further in Appendix I.

# APPENDIX F. SCRIPT FOR LINKING SCAFFOLD TO PANEL EXAMPLE

This example script for linking scaffold model to panel model is defined using the software *Grasshopper*, a plug-in for *Rhinoceros*, a popular digital modelling software among architectural designers. Steps that were used to create the digital model of the precedent building Suffolk University 20 Somerset Street by NBBJ (Suffolk) are described in this appendix.

## F.1 Regions

For the Suffolk model, there are three main regions of the façades, by level; the first two levels are all glass, floors three through five are the first region of precast, floors six through nine are the second region of precast. The exterior surfaces are created by extruded the basic plan shape (the *Base* input for the *Extrude* node in Figure 173a). *B* in the multiplication node is the floor to floor height. The basic plan shape is then moved and extruded again for levels three through five and size through nine. The upper two surfaces have an addition node *Custom Preview*, which uses an input *Swatch* to define a color to represent the extent of the region.




a

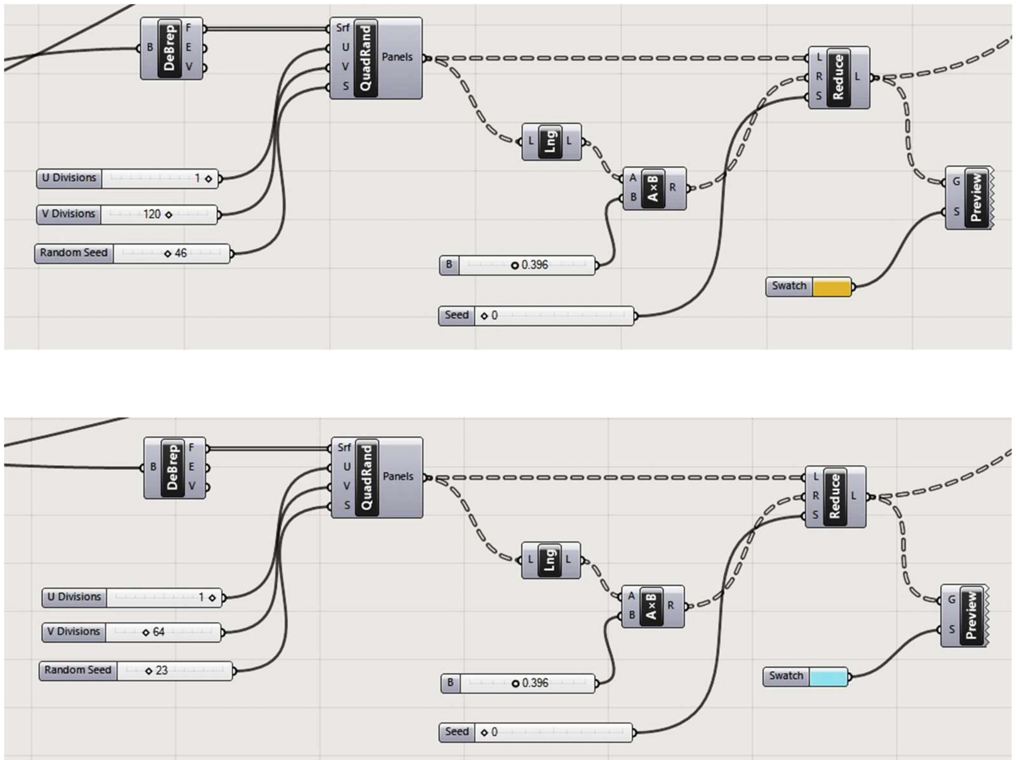
b

c

**Figure 173: Suffolk visual scripting definition – Regions**

## F.2 Regions within regions

An additional pattern is applied to each of the regions; *Random Quad Panels.* Then, the number of panels is reduced using *Random Reduce.* The *Reduction* input control the percentage of panels removed from the output list, while the "seed" variable permits the user to flex the distribution of random panels, allowing for some control.




a

b

**Figure 174: Suffolk visual scripting definition – Regions within regions**

## F.3 Exporting data and applying panel family

Data regarding each of the individually defined panels is exported from *Rhino* and *Grasshopper* to *Microsoft Excel.* Coordination of each corner of the panels are subsequently imported into *Dynamo* where a predefined architectural precast concrete panel family model is applied via *Revit*, allowing the user to customize the panel details and parameters. The Suffolk panel model definition is described in Section 5.1.1.1.

# APPENDIX G. SCRIPT FOR LINKING PANEL TO SCAFFOLD EXAMPLE

This example script for linking panel model to scaffold model is defined using the software *Grasshopper*, a plug-in for *Rhinoceros*, a popular digital modelling software among architectural designers. Steps that were used to create the digital model of the precedent building Armstrong Rubber Company Headquarters (Armstrong) by Marcel Breuer and Robert F. Gatje are described in this appendix.

## G.1 Bounding box

A bounding box is the three-dimensional equivalent of the panel boundary used to link models from scaffold to panel. For panel to scaffold mapping, a three-dimensional form is already instantiated. The bounding box is an abstraction of the more-complex and specific panel features that will be oriented across the building model surface.

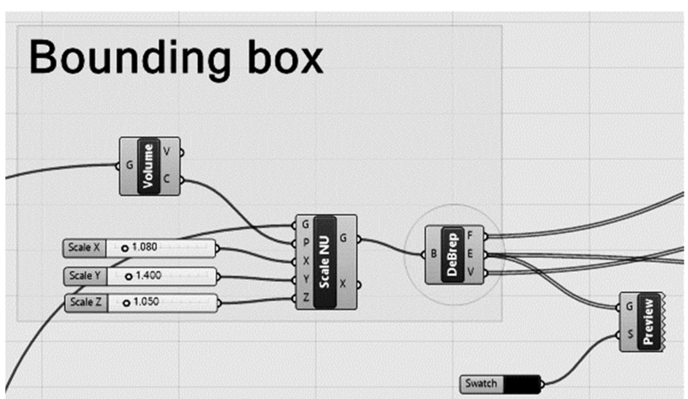



**Figure 175: Bounding box definition**

## G.2 Orienting panel to surface pattern

The script shown in Figure 176 simultaneously defines a surface and places panels upon it. This occurs because the dimensions of the surface as a factor of the dimensions of the panel as discussed in Section 5.1.2.1. *Number Sliders* define the number of panels horizontally and vertically. The building surface is then scaled to these proportions. A pattern can then be applied to the surface – in this case a regular grid – which defines panel boundaries. The *Orient* node then places panels within each boundary. More complex patterns of methods of orientation could be explored. Some examples are shown in Section 5.2.2.

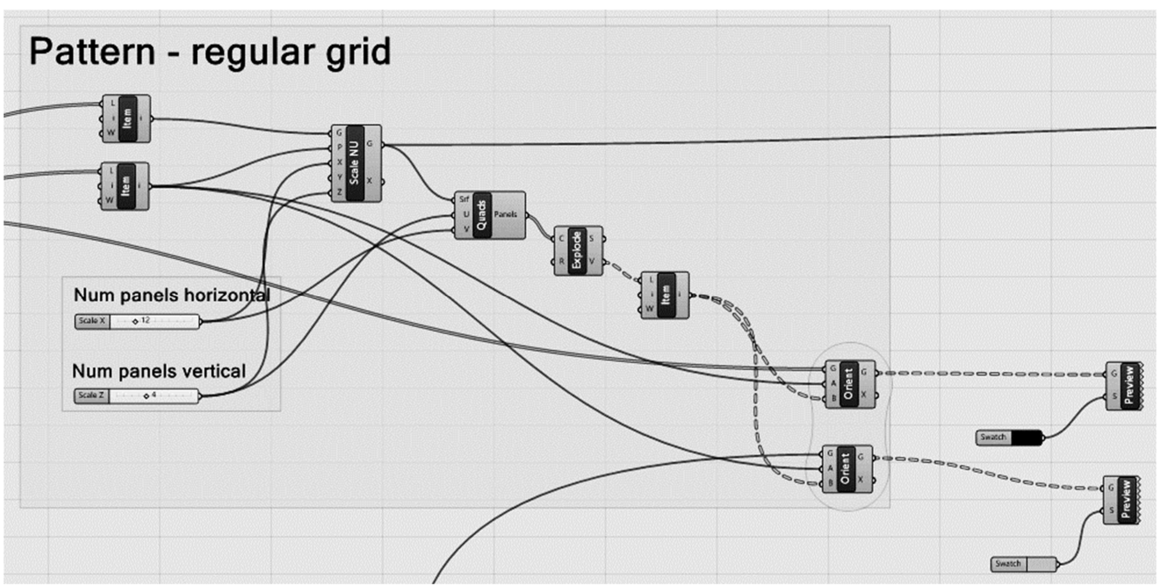



**Figure 176: Script orienting panel to surface pattern**

## G.3 Deriving scaffold variables

The script shown in Figure 177 is used to make the graphic representation of the scaffold models in Figures 98a and 98b. The intent is for use in discussion of the relationship between panel, surface, and the scaffold model. Especially important are the variables "Floor to floor height," "Scaffold in Y direction," and "Scaffold in Z direction." These values can then be passed to the main scaffold model and aid in coordination.

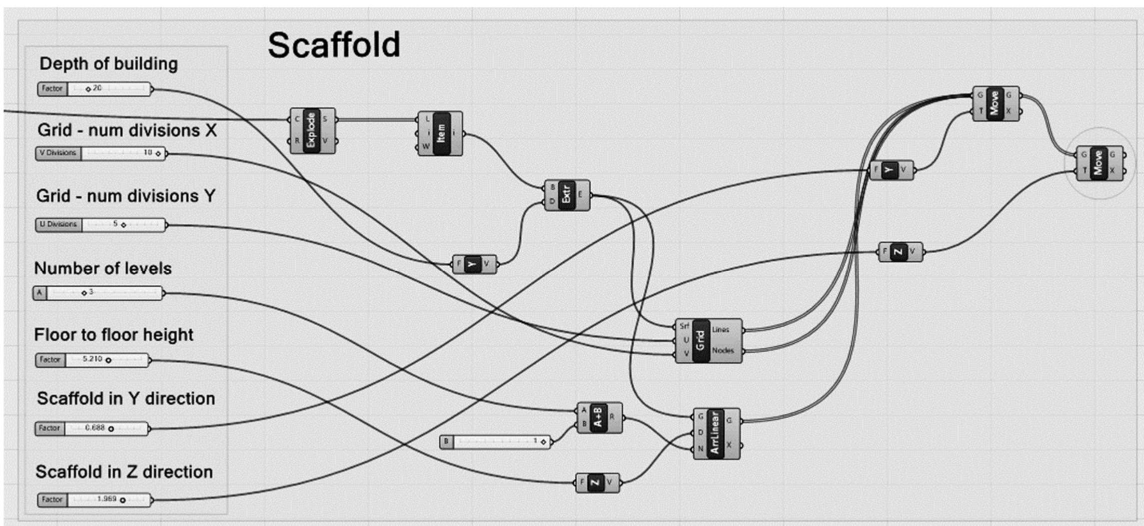



**Figure 177: Script deriving scaffold variables**

# APPENDIX H. SCRIPT FOR PANELIZATION EXAMPLE

This example script for modelling panelization is defined using the software *Grasshopper*, a plug-in for *Rhinoceros*, a popular digital modelling software among architectural designers. Steps that were used to create the digital model of the precedent building Philadelphia Police Department Headquarters (Roundhouse) by Geddes, Brecher, Qualls and Cunningham are described in this appendix.

## H.1 Panel boundaries

When creating a surface pattern for Roundhouse, one would most likely assume three vertical panels. These can be defined via a standard *Quad Panels* node. Later, this geometry will be used to define reveals in the panel surfaces rather than joints between panels.

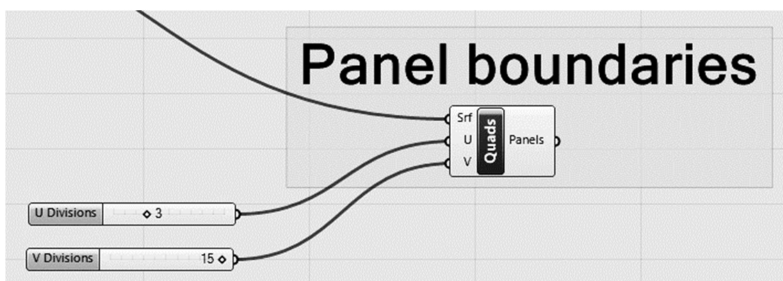
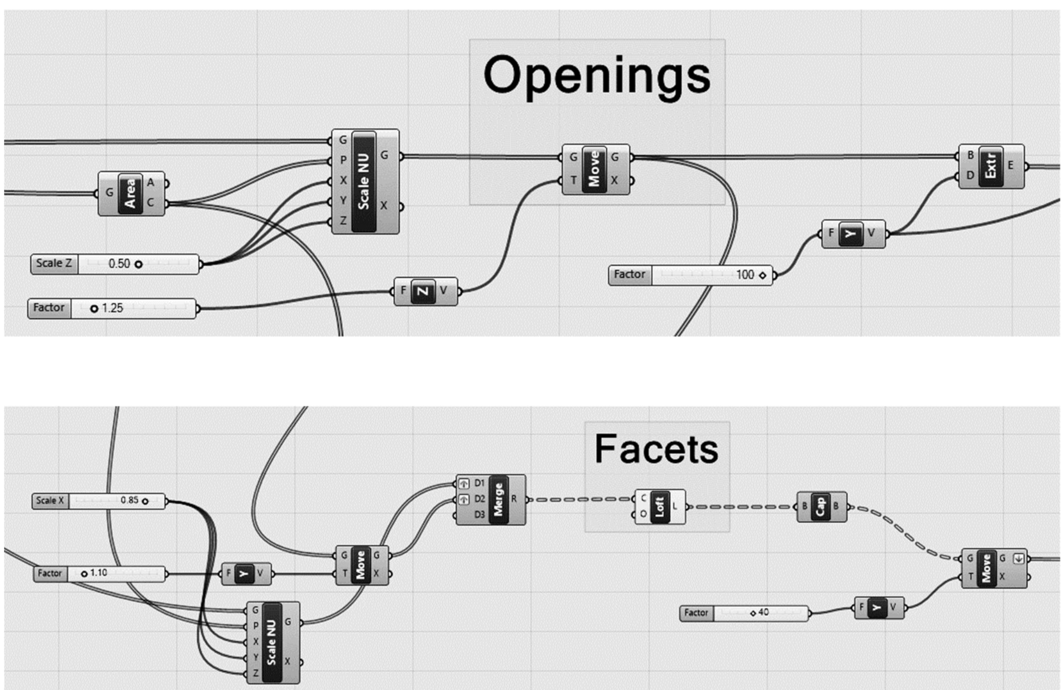



**Figure 178: Defining panel boundaries**

## H.2 Panel feature data

Next, data regarding the features of individual panels is collected and applied to the building surface. For the example model shown in Figure 100, all panels have the same features; facet + opening. Both of these are created by defining a series of solids that are *Booolean Differenced* from the building model surface. The openings are a *scaled* copy of the previously defined panel boundary which is then *moved* in the *Z* direction. Because the geometry of the openings and facets are linked, the facet also begins with a *scaled* copy of the panel boundary which is then *moved* in the *Y* direction. These scaled copies can then be *lofted* and *capped.*




a

b

**Figure 179: Defining panel feature data – openings (a) and facets (b)**

## H.3 Panelization 1

Finally, another layer of *Quad Panels* is used to define joints between panels. Through a series of operations illustrated in Figure 180, these vertical lines are used to *Boolean Difference* the building model surface, thereby creating individual panel. These individual panels can then be further customized with additional features.

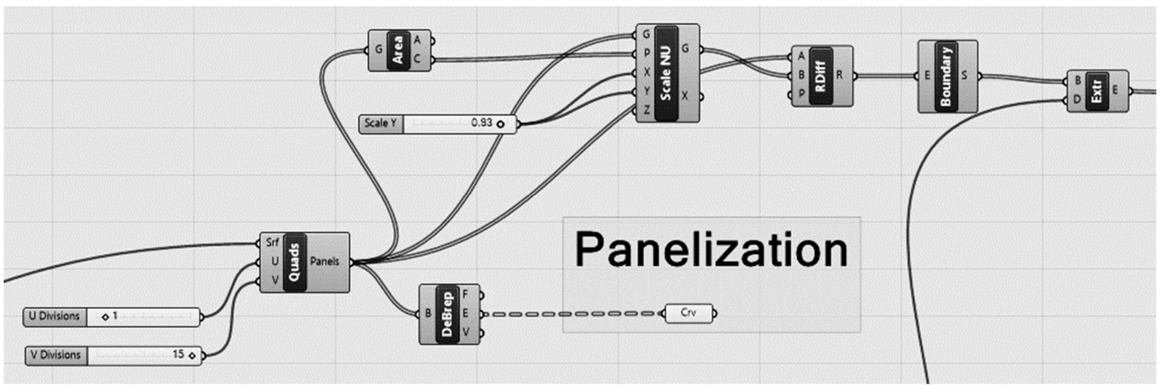



**Figure 180: Defining panelization 1**

# APPENDIX I. SCRIPT FOR PATTERNS ACROSS PANELS EXAMPLE

This example script for creating patterns across panels is defined using the software *Grasshopper*, a plug-in for *Rhinoceros*, a popular digital modelling software among architectural designers. Steps that were used to create the digital model of the precedent building 150 Rouse Boulevard by Digsau are described in this appendix.

## I.1 Panelization 2

Similar to Roundhouse, for 150 Rouse Boulevard, *Quad Panels* also define joints between panels through a series of operations illustrated in Figure 181.

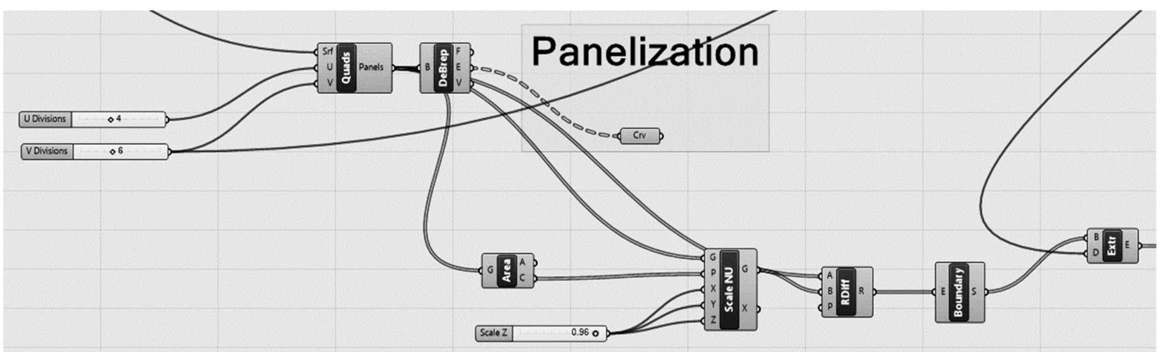
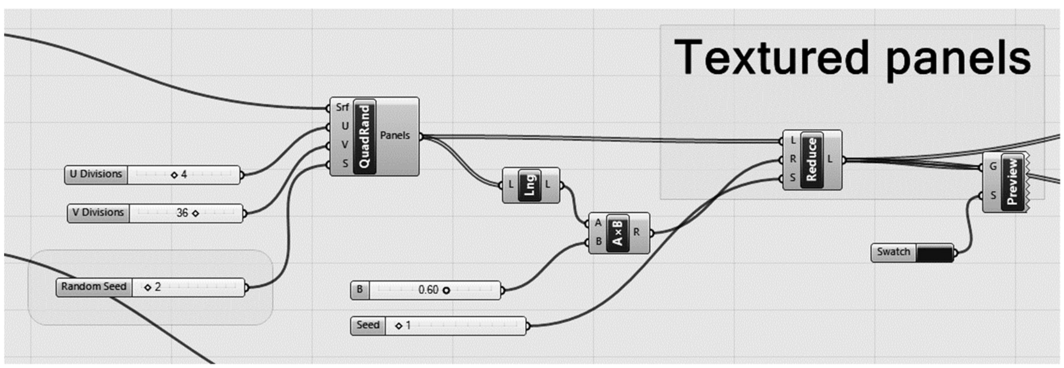


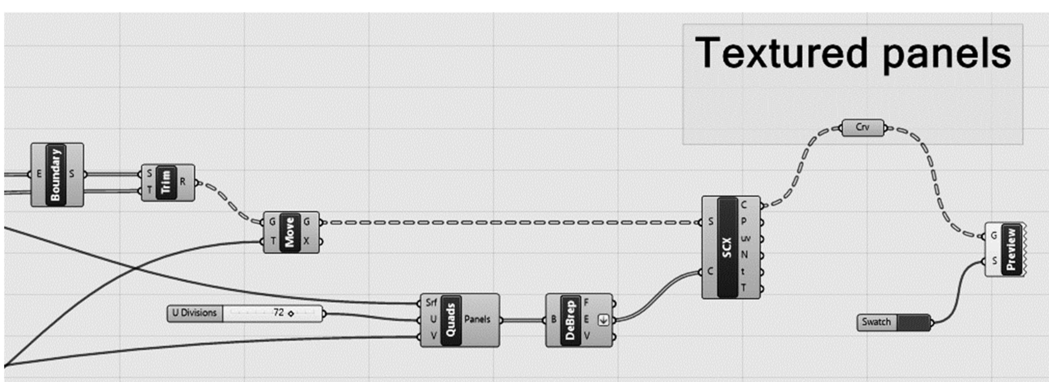

**Figure 181: Defining panelization 2**

## I.2 Pattern 1

The façade design for 150 Rouse Boulevard consists of two distinct patterns. First, a *Random Quad* pattern describes textured relief areas. Input variables for the *Random Quad* node include the number of divisions vertically and horizontally across the surface as well as a *Random Seed* which permits the user to flex the distribution of panels, allowing for some control of the pattern. The number of panels is the *Reduced* by a controllable amount to leave some areas of the surface without relief. These panels are *Boolean Differenced* from the building model surface. Finally, a *Quad Panel* is used to graphically texture the portions of the surface in relief.




a




b

**Figure 182: 150 Rouse Boulevard visual scripting definition – Surface pattern 1**

## I.3 Pattern 2

For the second pattern, openings are randomly populated across the surface. The first step uses the *Populate 2D* to broadcast a series of points onto the building model surface. Input variables for the *Populate 2D* node include the number of points and a *Seed* which permits the user to flex the distribution of points, allowing for some control. These points are insertion points for the *Polygon* shape of the openings. A *Random* node connected to the size input of the polygon allows for various size openings. These are *Boolean Differenced* from the building model surface.

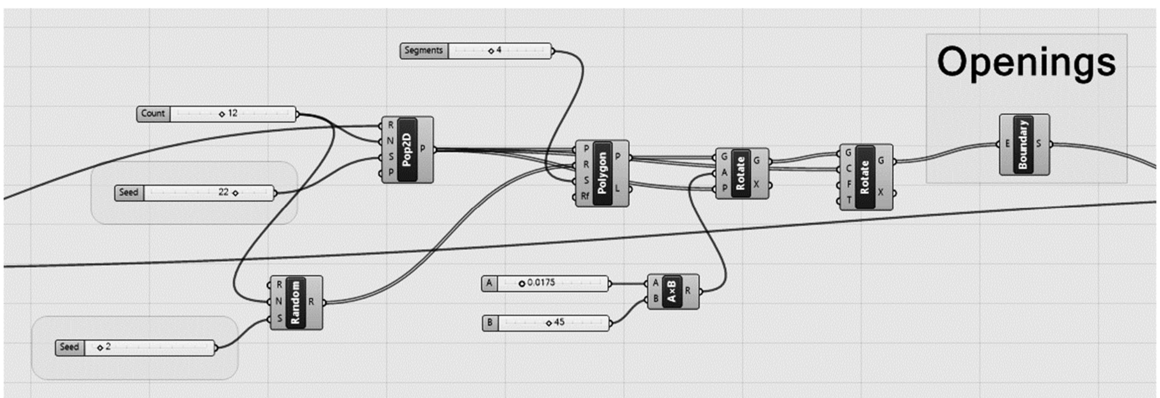



**Figure 183: 150 Rouse Boulevard visual scripting definition – Surface pattern 2**

# APPENDIX J. STUDENT QUESTIONAIRE RESPONSES

During the Spring 2018 semester, I shadowed a design studio in the Master of Architecture program in the School of Architecture at Georgia Tech. The studio, taught by Professor Tristan Al-Haddad, was focused on developing proposal for precast concrete buildings. Towards the end of the semester, I did interviews with them regarding their experience designing a precast concrete building, working with digital models.

The following common terms and definitions were given in order to be able to compare projects:

| | |
|---|---|
| *Bay depth* | Span of structural members (in direction of members) |
| *Bay width* | Distance between parallel structural members (perpendicular to members) |
| *Façade composition* | Regions different panel types or materials |
| *Façade panelization* | Joints between individual precast panels |

## J.1 Group 01 (Scheme 01)

Students: Bailey Rummler, Leila Moghimi, Shiyang Zhai

1. Tell me the shape of your building.
   It has 4 sides that aren't the same. Polygon with cut-outs and staggering.
2. Could you draw a sketch of that shape?

[Sketch informed models described in Section 6.1]

3. What factors influenced the decision of that shape?

   We have a 6-step diagram. Street that is disconnected (16th street). Go towards the edge of the site. Marta. Keep site safe. Lift up to create perforated spaces to connect to high and future art walk and allow permeation. We have rings/circuits because of parking. We staggered one wall to create shaded spaces and some exterior spaces for the hotel.

4. Because this is a precast building, are there modules?

   For the façade, and precast columns, and double tees. Based on the shape of the site, we were trying to do things that felt right. That limited what we could do. We have precast stairs.

5. What is your typical bay depth?

   60 feet.

6. What is your typical bay width?

   26 feet.

7. How has your grid been established?

   60 feet was based on hotel rooms with hallway in between. 26 feet is based on hotel room. And where corners and bridges and what would be a good distance to break up between.

8. How many floors does your building have?

   10.

9. Describe the floor stacking strategy.

   First floor is retail/Marta/lobby of hotel. Those spaces are double height. 3 through 8 are hotel rooms. 9 and 10 are gym, restaurant. It's kind of a sandwich. Rooftop is park.

10. How is your floor stacking strategy endorsed by precast?

    It isn't. Our stacking strategy could be done with any kind of building. Precast has dictated some of the regularity.

11. What additional factors influenced the building form?

Building around the site. High Museum and skyscraper across street. That is why the tallest part of our building is on West Peachtree. Park on the roof.

12. What is the floor to floor height?

    13 feet.

13. What is the overall building height?

    138 feet.

14. What is the relationship between your façade panels and the buildings' structural elements?

    There are really big columns and there are frames that brace between the columns. There are L-shape connectors that attached to the frame and the back of the panels.

15. How was your façade composition conceived?

    Our building staggers, so we wanted to play with the light that got into the different rooms of the hotel. We wanted a façade that could be broken down in a small number of panels as possible. We found a precedent that was made of twisting aluminum panels and tried to do the same in concrete. A stripe of the building is a bit more open is where the public space is. We wanted to show where the bridges are. We punched through to show those. We pulled the façade up over the ground floor to it is all open to the public.

16. What patterns define façade panelization?

    All of our panels connect top and bottom. They never have a side connection. They're basically strips.

17. Are there any other factors that control your façade designs?

    Sunlight going through. At the top, we wanted to have it more closed for the park. There's also mesh to keep things, like basketballs, from flying down.

18. Has the requirement of making a digital model limited or effected your design intentions?

    We are so used to making a model. Though I think *Revit* helped to make floor plans faster.

19. If so, how?

    Our façade was good to do in *Rhino*; you can loft. That was essential.

20. Have you used any "work-arounds" to supplement current CAD (in)abilities?

Using *Revit* to make floor plans. Doing that in *Rhino* is significantly harder.

21. Would your building be different if it were structural steel or cast in place?

    Yes.

22. If so, how?

    The façade would be much easier and thinner. And it would be lighter (the façade). We wouldn't need to beef up the columns. We did use steel trusses for our bridges. We chose to do that for the lightness of that structural system.

## J.2 Group 02 (Scheme 02)

Student: Mitra Maghsoudloo

1. Tell me the shape of your building.

   Box on top of a ring that wraps a green courtyard

2. Could you draw a sketch of that shape?

   [Sketch informed models described in Section 6.2]

3. What factors influenced the decision of that shape?

   First, I was trying to connect the High Museum side with outside and activate the street between them by bringing in some program like restaurants. As a hotel, I was thinking that the building should have character. I was trying to unify the structure and façade system. It is a diagrid and triangular panels.

4. Because this is a precast building, are there modules? (Describe briefly)

   Yes. Unified structure and façade system. 9 different panels, including 2 different corner panels.

5. What is your typical bay depth?

   60 feet.

6. What is your typical bay width?

   15 feet.

7. How has your grid been established?

    Regular size of hotel room. Standard slabs, custom façade panels.

8. How many floors does your building have?

    13.

9. Describe the floor stacking strategy.

    2 floors of ring, first floor is 25 feet tall, the second 12.5 (same basic shape).
    11 floors of 12.5 feet high (same basic shape).

10. How is your floor stacking strategy endorsed by precast?

    Spans work for precast lengths.

11. What additional factors influenced the building form?

    Façade is not flat surface, more dynamic ins and outs.

12. What is the floor to floor height?

    (See question 9)

13. What is the overall building height?

    175 feet.

14. What is the relationship between your façade panels and the buildings' structural elements?

    Façade panel are part of the structure. They wrap the building. They hold the double tees.

15. How was your façade composition conceived?

    Completely a diagonal pattern.

16. What patterns define façade panelization?

    Triangle. Connected by chamfered corners.

17. Are there any other factors that control your façade designs?

    Room dimension. Depth for balcony or shading element. Floor height. Aesthetic aspects.

18. Has the requirement of making a digital model limited or effected your design intentions?

No. Started with diagrid in *Grasshopper*. Switched to triangles. Customizing panels using *Rhino*.

19. If so, how?

    n/a

20. Have you used any "work-arounds" to supplement current CAD (in)abilities?

    Yes. Hadn't work on façade panel design. Figuring out how to connect them looking at precedents, copy and use them.

21. Would your building be different if it were structural steel or cast in place?

    Yes.

22. If so, how?

    A benefit of precast is the ability to span 60 feet. If it was cast in place, it could have more curves. In precast, you should limit the number of panels.

## J.3 Group 03 (Scheme 03)

Students: Sophie Brooks, Chris Landry, Yi Zhang

1. Tell me the shape of your building

   We have a lot of buildings. The primary building overall shape is a rectangular prism. We follow various site angles. The center does have some irregularity.

2. Could you draw a sketch of that shape?

   [Sketch informed models described in Section 6.3]

3. What factors influenced the decision of that shape?

   Mostly site factors. Our requirements for parking. Attitude toward West Peachtree. Site lines from High Museum. Rail lines below.

4. Because this is a precast building, are there modules?

   Yes. Core model is based on 2 standard parking spaces and 1 floor to floor height.

5. What is your typical bay depth?

60 feet.

6. What is your typical bay width?

18 feet.

7. How has your grid been established?

18 was established by parking spaces.
60 is from double tee, not too wide for double loaded corridor.

8. How many floors does your building have?

14.

9. Describe the floor stacking strategy.

Ground floor is retail and hospitality and Marta. Middle floors are parking then hotel rooms. Roof is night club and entertainment and pool. When it's a hotel, that the amenities.

10. How is your floor stacking strategy endorsed by precast?

Precast is modular, hotels are modular. Modular program is good for precast. Anything that can be repeated.

11. What additional factors influenced the building form?

Main site factor is the Marta rail lines. West Peachtree Street.

12. What is the floor to floor height?

12 feet.

13. What is the overall building height?

184 feet.

14. What is the relationship between your façade panels and the buildings' structural elements?

The panels are the structural elements. Instead of using spandrels, the panels become arches and the double tees sit on them.

15. How was your façade composition conceived?

We took inspiration from medieval stonework and arches. Frames of single rooms and providing balcony space on top of the panels.

16. What patterns define façade panelization?

Arch and half offset. It was demising walls between rooms but that evolved.

17. Are there any other factors that control your façade designs?

    Desire to shade and perhaps passively cool.
    We squared off some edge thinking about formwork. Minimal panel types.

18. Has the requirement of making a digital model limited or effected your design intentions?

    Yes.

19. If so, how?

    It probably pushed us to using parametric designs. And generating iterations. We used scripting to show it fast. That was limited by what we knew.

20. Have you used any "work-arounds" to supplement current CAD (in)abilities?

    We got it to do what we wanted it to. Eventually. There may be possibilities that we did not explore but we are limited.

21. Would your building be different if it were structural steel or cast in place?

    Yes.

22. If so, how?

    If structural steel, we wouldn't be limited by the structural panels. It could be more of a screen.
    The arrangement we chose is based on it being structural. The façade expression could be very different. We could have more variations.
    I think the shape of the building became a constraint; easily available dimensions. We could have chosen others.

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